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Sewage Sludge Incinerator Fuel Reduction at Nashville, Tennessee

Battelle Columbus Labs., OH

Prepared for

Municipal Environmental Research Lab.
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16. ABSTRACT

This is a report on the sewage sludge incineration fuel reduction program at the Nashville-Davidson County Metropolitan Government wastewater treatment plant in Nashville, Tennessee. Fuel usage was reduced over 40 percent by reprogramming the methods used for operating the incinerators and by an operator training program. The purpose of the report is to confirm that the 45 to 75 percent fuel savings demonstration at the Indianapolis, Indiana, Belmont Wastewater Treatment Plant incinerator is not limited to the Belmont Plant, but can be accomplished at all sewage sludge incinerator plants in the United States.

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SEWAGE SLUDGE INCINERATOR FUEL REDUCTION AT NASHVILLE, TENNESSEE

by

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Contract No. 68-02-3487

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communication link between the researcher and the user community.

Incineration of sewage sludge is an ultimate disposal option that provides an inert, safe, minimum-volume residue that minimizes ultimate landfill requirements. This disposal method is expected to find increasing use as landfill sites become less available and as ocean disposal is discontinued. Auxiliary fuel requirements for incinerators are of great concern because of the increasing costs of all fossil fuels. This report presents the results of a field demonstration project to reduce fuel consumption in municipal sludge incinerators by using a more fuel efficient operating mode.

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ABSTRACT

A field demonstration project was conducted to reduce fuel consumption in municipal sludge incinerators by using a more fuel-efficient incinerator operating mode. The Nashville Department of Water and Sewerage Services demonstrated the new operating mode at its Central Wastewater Treatment Plant Incineration Facility in Nashville, Tennessee, usirg two conventional multiple hearth sludge incinerators.

The more fuel efficient incinerator operating mode was developed from an extensive program of combustion engineering measurement, testing, and operational analysis. Incinerator operators were then given on-the-job training in the new operating mode during a 30-day demonstration period. After 10 months of routine operations in the new operating mode, a fuel reduction of more than 40 percent was achieved, representing an annual fuel cost savings of approximately $350,000 per year.

The project demonstrated that efforts to improve and optimize existing incinerator operating modes are very cost effective.

This report was submitted in fulfillment of Contract No. 68-02-3487 by Battelle Columbus Laboratories under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period of April 1981 to April 1982, and work was completed as of June 1982.

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ENGLISH TO METRIC UNITS CONVERSION TABLE

English Unit	Metric Equivalent	Conversion Factor
Pound (lb)	Kilogram (kg)	0.4536
Short Ton (ton)	Metric Ton (m. ton)	0.9072
Cubic Feet (ft^3)	Cubic Meter (m^3)	0.0283
Gallon (U.S.) (gal)	Liter (ℓ)	3.785
British Thermal Unit (Btu)	Joule (j)	1055
Fahrenheit (^oF)	Centigrade (^oC)	5/9 (^oF - 32)

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ACKNOWLEDGMENTS

The successful results of this project were due in part to the appropriate application of combustion engineering operating technology to the Nashville Incinerator operations. Major credit goes to a very well managed plant operation and to the incinerator operators at the Nashville Central Wastewater Treatment Plant. The operators, having operated the incinerators for many years, were receptive to learning and using the new operating approach. Special recognition is due to these individuals for their cooperation and performance: Mack Butler, Ed Franklin, Grady Hale, Hubert Prater, and James Renfro.

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SECTION 1

INTRODUCTION

The disposal of municipal sewage sludge by incineration most often requires the use of major amounts of auxiliary fuel. Increasing energy costs have made incinerator fuel consumption a major operational cost problem for many municipal operations. The objective of this project was to demonstrate how incinerator fuel consumption could be reduced by developing and using a more fuel efficient operating mode. The Metropolitan Government of Nashville-Davidson County Department of Water and Sewerage Services conducted this demonstration project at its Central Wastewater Treatment Plant Incineration Facility with the technical assistance of the Indianapolis Center for Advanced Research.

A new, more fuel efficient operating mode was developed from combustion engineering analyses and reduced to practice. Fuel consumption performance tests were conducted to demonstrate possible reduction levels and to provide on-the-job training for incinerator operators.

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SECTION 2

CONCLUSIONS

1. Fuel consumption in multiple hearth municipal sludge incinerators can be significantly reduced by improving and optimizing existing operating modes with more fuel efficient operating techniques.

2. Use of the new operating mode in routine operations for a 10-month period showed a 40 percent fuel reduction and a reduction in equipment maintenance problems.

3. Fuel cost savings of approximately $350,000 were realized for the first year of operation. Further investment in instrumentation and controls for improved fuel flowrate and excess air control are expected to produce further savings.

SECTION 3

RECOMMENDATIONS

- Most municipal sludge incinerator operations are still experiencing high fuel consumption rates as a result of using improper incinerator operating modes. Further applications of improved operating techniques need to be promoted as a cost-effective approach to reducing incinerator fuel consumption.

- A comparative analysis of specific fuel consumption with sludge cake moisture and volatile characteristics for different municipal operations needs to be undertaken to exemplify the enormous fuel saving potential that still exists in many incinerator operations.

- Low cost investments for improved instrumentation and controls for air, fuel and load rate monitoring and control can result in major fuel savings for many existing operations.

SECTION 4

DESCRIPTION OF PREVIOUS OPERATIONS

SLUDGE CAKE CHARACTERISTICS

The Nashville Central Wastewater Treatment Plant performs primary and secondary wastewater treatment for more than 85 million gallons* of wastewater per day and generates in excess of 85,000 tons of wet sludge cake per year. The mixed primary and secondary (waste-activated) sludge is dewatered by vacuum filtration. Polymer conditioning is used to obtain solids flocculation for vacuum filtration. The Nashville sludge cake, compared with that of other cities, is relatively higher in moisture content and lower in absolute volatile content. Table 1 compares sludge cakes from Nashville with several other cities. Among the cities shown, the Nashville sludge cake has the highest cake moisture to volatile ratio (M/V), which is the key parameter that affects incinerator auxiliary fuel requirements.

INCINERATOR DESCRIPTION

Like most other cities using incineration for sludge disposal, Nashville uses multiple-hearth type incinerators. The City has two Nichols** incinerators and operates on a 7-day, 24-hour-a-day basis. The incinerators are 22.3 feet in diameter and 41.3 feet in height. Each incinerator has 10 ceramic hearths. The design load rate is 10.0 wet tons of sludge cake per hour. The Nashville incinerator system is shown schematically in Figure 1. Nashville also has two older seven-hearth incinerators that are only used for back-up operations.

Sludge cake enters the incinerator through a top mounted drop chute. The sludge cake is moved down through the incinerator, from hearth to hearth, by rabble arms with raking teeth connected to a rotating center shaft. The sludge cake dries in the upper hearths by exposure to the high temperature combustion gases and then burns on the middle hearths. The hot ash cools and is discharged from the bottom of the incinerator where it is water quenched. The central shaft and rabble arm are air-cooled and the heated cooling air emerges from the incinerator at 150°C (300°F).

---

*English units are used in this report since it contains existing equipment operating information to aid other City operators.

**Use of trade names does not constitute an endoresement.

TABLE 1. SLUDGE FILTER CAKE COMPARISON

Characteristic	Nashville	Indiana-polis	Detroit	St. Paul	St. Louis	Fairfax County Virginia	Average
Moisture (Wt %)	82.8	65	77	73	72	80	77
Volatile (Wt % of Solids)	62.2	30	50	48	56	60	55
Volatile (Absolute Wt %)	10.7	10.5	11.5	13	15.7	12	12.5
Moisture/Absolute Volatile	7.7	6.2	6.7	5.6	4.6	6.7	6.1

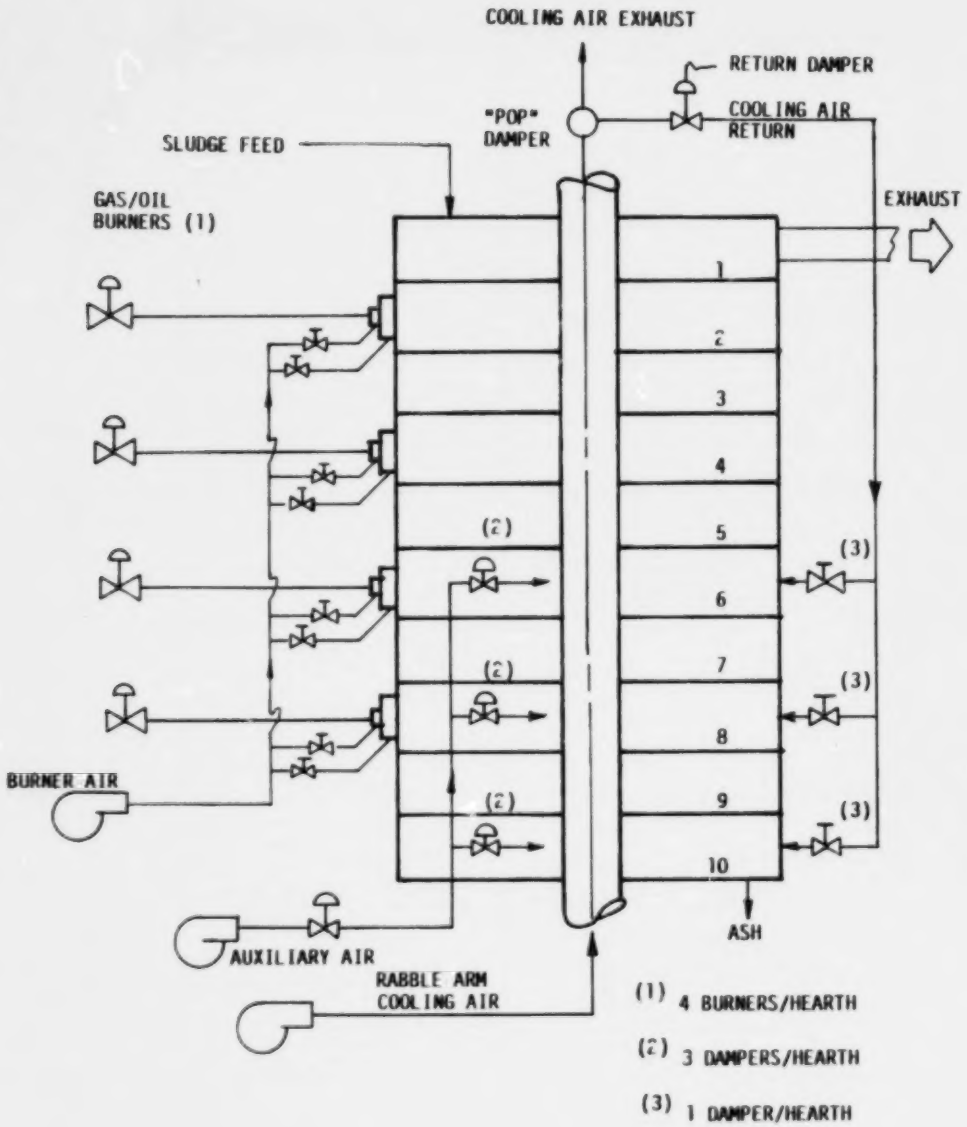

Figure 1. Nashville Incinerator System Schematic

The incinerator has sixteen dual-fuel, gas or oil fired burners with four of each located on hearths 2, 4, 6 and 8. The burners are excess-air type burners, with constant atomizing and combustion airflow over the firing range. The atomizing and combustion airflows are adjustable at each burner. Additional air can also be supplied by the heated rabble arm return air, auxiliary combustion air and through open hearth doors and peep holes. As shown in Figure 1, the heated rabble arm cooling air can be returned to the incinerator at the 6, 8 or 10 hearth levels, or discharged to the atmosphere. The auxiliary combustion air fan supplies air to three dampers each on hearth levels 6, 8 and 10. Air may also be drawn through hearth doors and peep holes located on each hearth.

Instrumentation

The Nashville incinerators are equipped with the following principal instruments:

- Center shaft speed rpm indicator
- Draft in the exhaust duct
- Incinerator draft on 10 hearth
- Oxygen content of the exhaust gas flow (recorded)
- Combustible content of the exhaust gas flow (recorded)
- Temperature on each hearth level (recorded)
- Cooling air inlet and exit temperature (recorded)
- Auxiliary air pressure
- Burner air pressure
- Cooling air pressure
- Sludge cake feedrate
- Sludge cake total weight
- Sludge cake moisture (off-line, periodic)
- Burner on/off indication
- Burner firing rate indication
- Auxiliary air damper position indication
- Cooling return damper position indication
- ID fan inlet damper position indication

In addition to the above, other instruments are available for the exhaust system and the fuel handling system.

Controls

The incinerators are equipped with the following principal remote incinerator controls:

- Center shaft speed control
- Draft control (such as ID fan inlet damper control)
- Exhaust oxygen control
- Burner firing rate control, manual or automatic to temperature set points. All burners on a hearth are controlled together, although burners may be individually shut off.

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- Cooling air return damper
- Auxiliary air pressure
- Auxiliary air damper position. Auxiliary air dampers on each hearth are controlled together.

Other incinerator controls may be positioned by hand:

- Cooling air return dampers on hearths 6, 8 and 10
- Incinerator doors and peep hole positions.

OPERATING PROCEDURES

There was no common operating procedure being used by the Nashville incinerator operators. Each operator had certain specific practices and techniques for maintaining temperatures on various hearth levels and for managing incinerator airflow. Preliminary investigations of the operator-specific operating modes identified several common operating problem conditions relative to fuel consumption. These were

- incinerator exhaust temperatures were too high
- combustion zone location was too high in the incinerator
- incinerator draft was greater than necessary
- heated rabble arm cooling air was under utilized
- auxiliary air supply was being over used
- burner use patterns were not optimum

Other problem areas as well as the management of the sludge cake loading to the incinerators were also contributing to high fuel consumption. These factors are discussed in more detail in Sections 5 and 6.

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SECTION 5

OPERATIONAL MEASUREMENTS AND ANALYSIS

AIRFLOW MEASUREMENTS RESULTS

Measuring ports were made on all the airflow ducts of both Nashville incinerators to enable the principal airflows to be measured by ICFAR combustion engineers. The airflow and exhaust gas measuring points are illustrated in Figure 2 and included the following locations:

- Cooling air return duct
- Cooling air inlet duct (two locations)
- Cooling air exhaust stack
- Auxiliary combustion air ducts (three locations)
- Burner air ducts (four locations)
- Exhaust stack duct (oxygen analysis)

Airflows were measured with pitot/static probes and sensitive pressure gauges (accuracy to 0.01 inches of water). Seven-point surveys were accomplished at each duct to provide accurate airflow measurement, in spite of possible flow distortion. The pitot tube immersions were selected for approximately equal flow areas.

Airflows were calculated using the following equation:

$$W = 0.0397A\sqrt{\frac{P_T - P_S P_T}{T}}$$

where

W = Duct airflow (lb_m/sec)

A = Duct flow area (in^2)

P_T = Total pressure (in water)

P_S = Static pressure (in water)

T = Absolute temperature (^oR)

Standard atmospheric pressure

The airflow measurements were made with only minor flow distortions found

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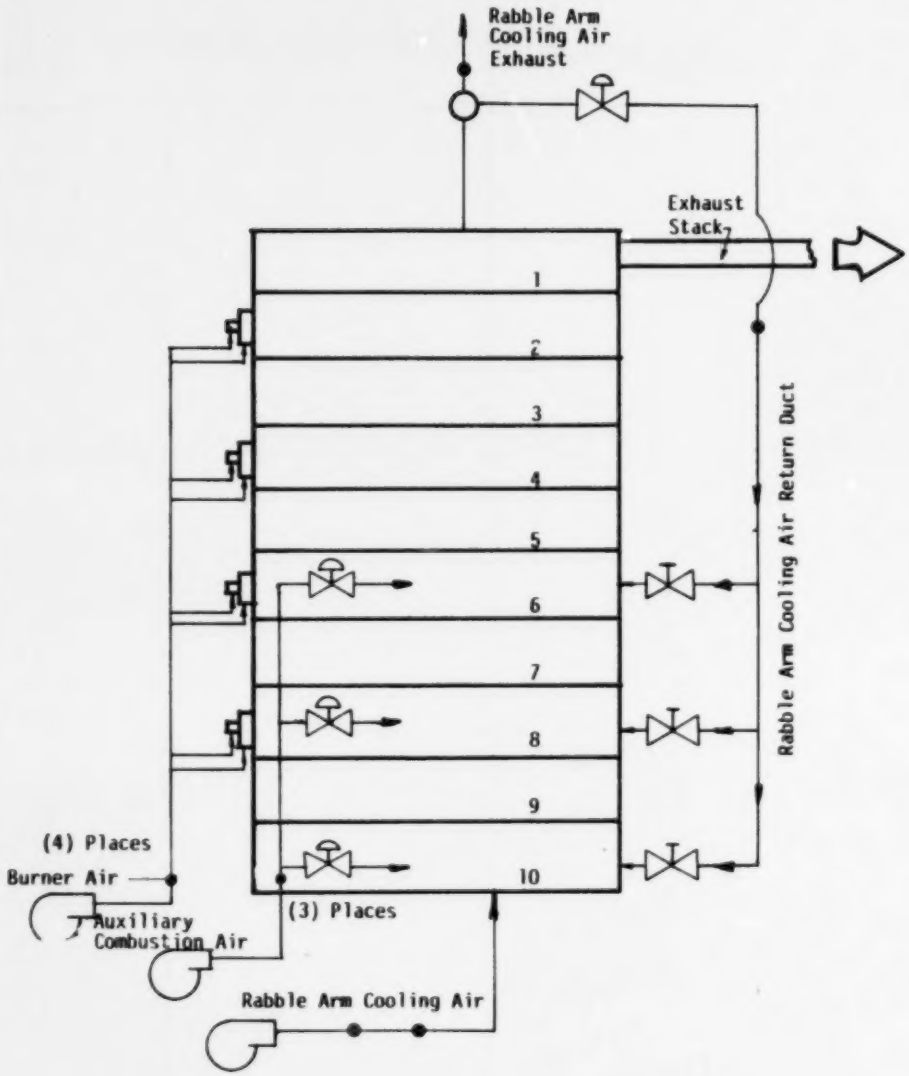

Figure 2. Airflow Measurement Locations

in the ducts. The results of the airflow measurements are summarized in Figure 3. The oxygen analysis in the exhaust gas was measured with an oxygen analyzer having an "in-situ" zirconium oxide cell which provides a wet-basis oxygen analysis. The key burner pressures were also measured. Significant variations were found from burner to burner.

The incinerator operating conditions when these measurements were made are shown in Table 2.

ANALYSIS OF AIRFLOW MEASUREMENTS

The excess air based on measured airflow was compared with the excess air from oxygen analysis. The excess air from measured airflow was determined from the following:

- Load = 21,175 wet lb/hr = 10.5 wet tons/hr
- Moisture = 83%
- Volatile = 70%
- Sludge volatile = 0.66 lb/sec
- 7.41 lb air/lb sludge volatile (stoichiometric)
- 21,000 $ft.^3$/hr natural gas
- 17.1 lb air/lb natural gas (stoichiometric)

On this basis, excess air from airflow was 0%, compared with 33% excess air from gas analysis. This is considered reasonable agreement, considering the estimated sludge characteristics, and other unknowns.

The airflow measurement results were analyzed for fuel reduction potential, relative to the following typical baseline operation:

- Load = 7 tons/hr
- Moisture = 82%
- Volatile = 60%
- M/V Ratio = 7.6
- Fuel Consumption = 2,250 $ft.^3$ of gas/wet ton
  = 12,250 $ft.^3$ of gas/dry ton
  = 15,750 $ft.^3$ of gas/hr

The changes in the operational mode derived from the airflow analysis and estimated fuel reduction potential from improved airflow management are described below.

The most obvious energy waste indicated by the airflow measurements was the rabble arm cooling air being discharged to the atmosphere. Assuming a burner heat availability of 73% at typical exhaust temperatures, 4.5 lb/sec cooling airflow represents 1,598 $ft.^3$ of gas/hr, or 10% of the fuel consumption. Since the oxygen measurement indicated a low excess air level

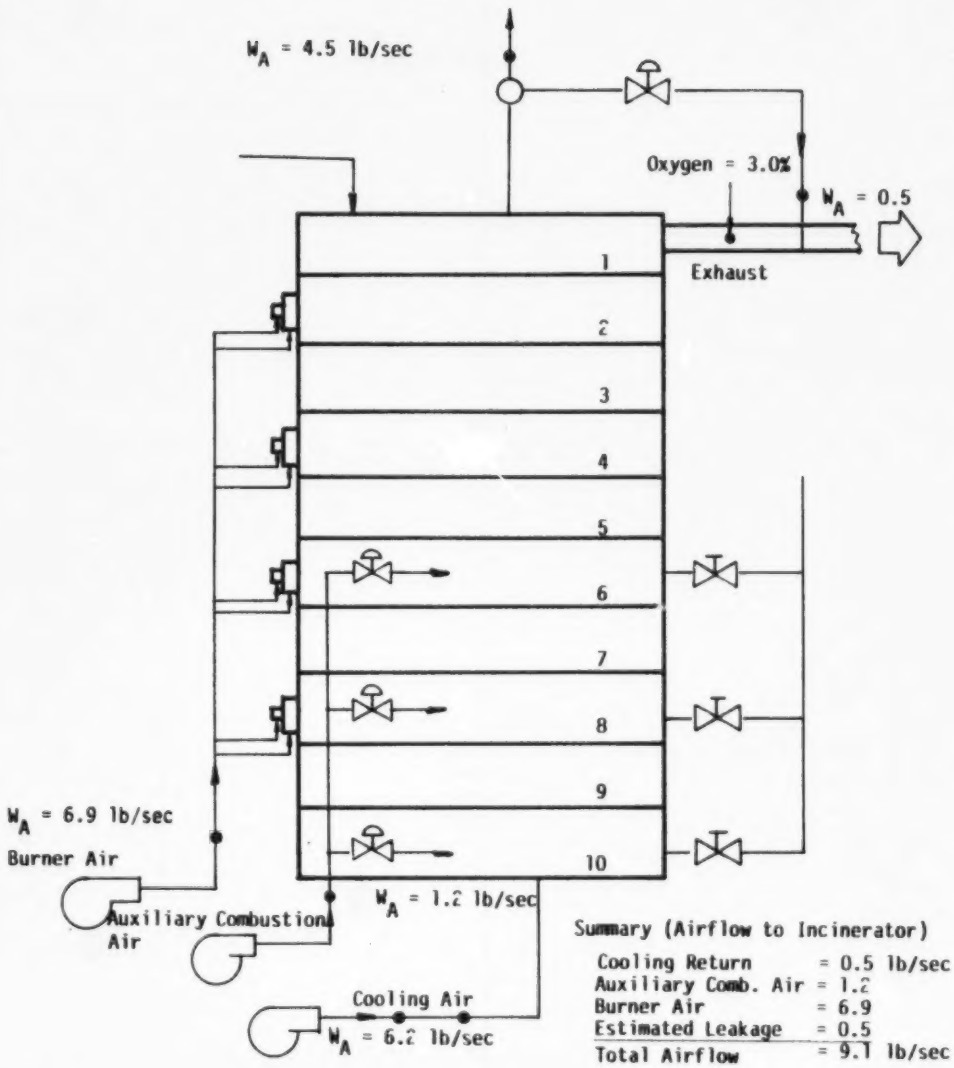

Figure 3. Incinerator Airflow Measurement Results

TABLE 2. INCINERATOR OPERATING CONDITIONS DURING MEASUREMENT PERIOD

Variable	Value
Sludge Cake Load	21,175 wet lbs/hr (10 wet tons/hr)
Cake Moisture	83%
Cake Volatile	70%
Temperatures	
Hearth #1	942°F
Hearth #2	1,048
Hearth #3	1,284
Hearth #4	1,347
Hearth #5	1,430
Hearth #6	1,358
Hearth #7	731
Hearth #8	346
Hearth #9	151
Hearth #10	74
Rabble Arm Cooling Air Exit	369°F
Draft	0.13 inches of water
Auxiliary Air Dampers	
Hearth #10	50% Open
Hearth #8	50% Open
Hearth #6	Closed
Cooling Air Return	25% Open
Rabble Arm Shaft Speed	0.60 rpm
Burners On	
Hearth #2	0
Hearth #4	4
Hearth #6	4
Hearth #8	1

of 33% (which cannot be significantly reduced), some cold incinerator air inflow would have to be reduced to allow the use of the heated rabble arm.

Replace Auxiliary Combustion Air With Heated Rabble Arm Cooling Arm

As shown in Figure 3, the auxiliary air is typically 1.2 lb/sec. The equivalent gas savings from this measure would be:

$$\frac{1.2\ \text{lb}}{\text{sec}} \times \frac{3600\ \text{sec}}{\text{hr}} \times 300^{\circ}\text{F} \times \frac{.24\ \text{BTU}}{\text{lb}^{\circ}\text{F}} \times \frac{1\ \text{ft}^3\ \text{of gas}}{1000\ \text{BTU}} \times \frac{1}{.73} = \frac{426\ \text{ft}^3\ \text{of gas}}{\text{hr}}$$

$$= 426\ \text{CFH}$$

This is an estimated fuel reduction of $\frac{476}{15,750} \times 100\% = 2.7\%$.

Shut Off Hearth 2 Burner Air

Heat from the hearth 2 burners can only dry the sludge on the top hearths, so it is best not to use these burners at all. Assuming rated flow of 13,970 ft^3/hr(CFH) for these burners per manufacturer's specs, the energy savings from this measure would be:

$$\frac{1.18\ \text{lb}}{\text{sec}} \times \frac{3600\ \text{sec}}{\text{hr}} \times 723^{\circ}\text{F} \times \frac{.24\ \text{BTU}}{\text{lb}^{\circ}\text{F}} \times \frac{1}{.73} \times \frac{2}{4} \times \frac{1\ \text{ft}^3\ \text{of gas}}{1000\ \text{BTU}} = 505\ \text{CFH}$$

Estimated savings = 3.2%.

Shut Off Hearth 4 Burner Air

The rationale for this measure is the same as for Hearth 2 burners. In fact, the savings is greater for the hearth 4 burners because the airflow is greater and the burner air chilling effect extends over 4 hearths. Assuming a rated flow of 19,370 CFH for these burners, the energy saving would be:

$$\frac{1.64\ \text{lb}}{\text{sec}} \times \frac{3600\ \text{sec}}{\text{hr}} \times 723^{\circ}\text{F} \times \frac{.24\ \text{BTU}}{\text{lb}^{\circ}\text{F}} \times \frac{1}{.73} \times \frac{2}{4} \times \frac{1\ \text{ft}^3\ \text{of gas}}{1000\ \text{BTU}} = 1403\ \text{CFH}$$

Estimated savings = 8.9%

Adjust Burner Air Pressures

Trial tests with the burners indicated that combustion air pressure could be safely reduced from the manufacturer spec of 8 to 5.8 ounces per square inch without burner overtemperature or excessive flame length. This measure would reduce burner airflow approximately 1.28 lb/sec from currently measured values. This cold air could then be replaced with heated rabble arm cooling air to provide energy reduction. The energy saving from this

measure is:

$$\frac{1.28\ lb}{sec} \times \frac{3600\ sec}{hr} \times 300^{o}F \times \frac{.24\ BTU}{lb^{o}F} \times \frac{1}{.73} \times \frac{1\ ft^{3}\ of\ gas}{1000\ BTU} = 454\ CFH$$

Estimated savings = 2.9%.

Move Sludge Combustion Zone From Hearth 5 to Hearth 7

Burning lower in the incinerator increases the sludge drying area so that the drying process can be completed at reduced temperatures with less fuel. The effect of combustion level is more fully discussed in Section 6. Estimated energy saving from this measure is 3,309 ft^3/hr, or a 21% fuel reduction.

Reduce Rabble Arm Cooling Air Exit Temperature

The previous measures will reduce temperatures throughout the incinerator, resulting in an estimated cooling air discharge temperature reduction from 377°F to 300°F. The energy saving is:

$$\frac{2.0\ lb}{sec} \times \frac{3600\ sec}{hr} \times 77^{o}F \times \frac{.24\ BTU}{lb^{o}F} \times \frac{1}{.73} \times \frac{1\ ft^{3}\ of\ gas}{1000\ BTU} = 182\ CFH$$

Estimated savings = 1.2%.

Other measures such as reduced center shaft speed, reduced excess air, reduced draft are more difficult to quantify but can provide additional fuel reductions.

In summary, the preliminary analysis of the airflow measurements indicated a total operational fuel reduction at these conditions of approximately 40% was possible.

STATISTICAL ANALYSIS OF BASELINE OPERATIONS

A statistical analysis was made of the Nashville incinerator operations for the historical period of January 1, 1978 through May 31, 1980 (29 months). This analysis was performed with a standard computer statistical package to:

(1) compute the baseline load rates, sludge cake characteristics and fuel consumption for past operations to provide a baseline for measuring the total percent fuel reduction achieved in the demonstration test, and
(2) determine operational correlations between specific fuel consumption and incineration load rates and sludge cake moisture to volatile ratio (M/V).

The operational data analyzed were supplied by the Department of Water and Sewerage Services and included daily values for the following:

(1) total wet pounds of sludge cake
(2) percent solids and moisture
(3) percent volatiles
(4) fuel used for incineration only (gas and/or fuel oil)
(5) fuel used for standby, also by type

Operational data were completed for a total of 800 days of the baseline period. These operational data were then used to compute specific fuel consumptions and load rates on a wet and dry ton basis. Fuel use was converted to equivalent BTU's to allow comparisons.

Nashville officials asked ICFAR to develop and demonstrate two new operating modes, a Full Operational Mode and a Standby Operational Mode. Past operations had involved, depending on the sludge load, two different operating modes: (1) both incinerators operating and no standby fuel use (Full Operational Mode days) and (2) one incinerator operating with the second placed on standby and maintained at a temperature of approximately 1000^{0}F (Standby Operational Mode days). For this reason, the statistical analysis of the baseline operations divided the base period days into either Full or Standby Operational days to enable a baseline fuel consumption to be determined for both modes and enable a subsequent comparison with the demonstration test results to the total percent fuel reduction.

The principal measure used for comparing fuel consumption was the specific fuel consumption (SFC) defined as cubic feet of gas per ton of sludge cake incinerated. The specific fuel consumption is also directly related to the absolute ratio of sludge cake moisture to volatile content by weight (lb/lb). An accurate comparison of specific fuel consumption must account and correct for the moisture to volatile ratio (M/V) of the sludge cake being incinerated to avoid a distorted comparison. For this reason, the relationship of the daily average specific fuel consumption and the sludge cake moisture to volatile ratio for the baseline period operations was computed to be compared to the same relationship recorded for the demonstration test to enable the specific fuel consumption comparisons to be made for a given sludge cake moisture to volatile ratio.

A least squares regression analysis was made for the specific fuel consumption versus sludge cake moisture to volatile ratios for the baseline time period. The result of this is shown in Figure 4 with the computed regression line superimposed. This known relationship was used to more accurately compare the specific fuel consumption results achieved during the demonstration test by accounting for the specific daily average moisture to volatile ratio of the sludge cake during each test day.

Table 3 gives the daily average values of the key operational variables for the baseline period, and Table 4 shows values by month. The small difference found between the daily load rates between full operational and standby mode days during the baseline period, about 15%, suggested that the sludge loading to the furnaces could be changed to minimize the need for standby operations. How the new operating mode enabled the sludge load management to be changed to minimize standby and reduce fuel consumption

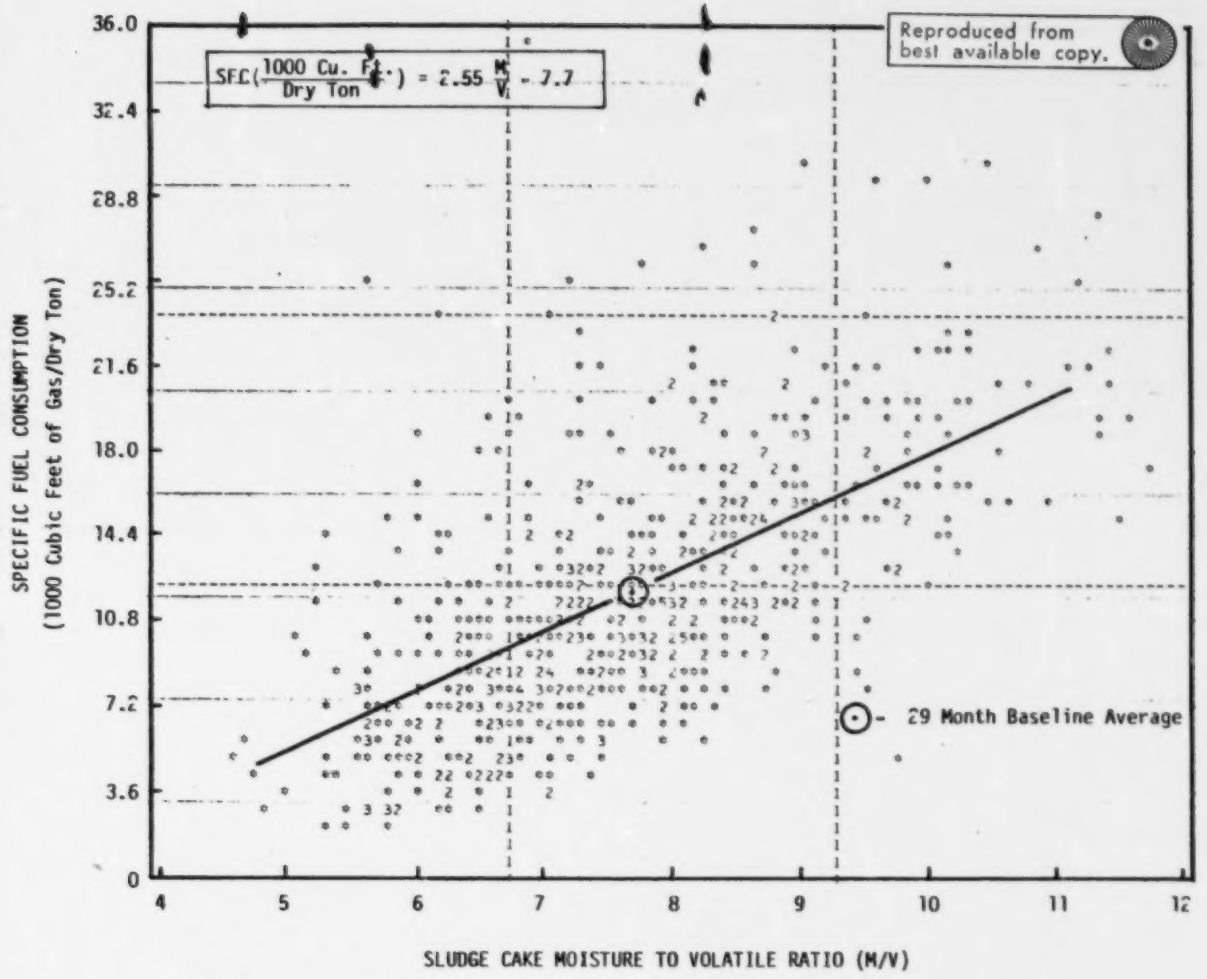

Figure 4. Specific Fuel Consumption for Baseline Period Operations

TABLE 3. BASELINE PERIOD DAILY AVERAGE VALUES FOR OPERATING VARIABLES

Operational Variable	Daily Average Values: All Days	Full Operational Mode Days	Standby Mode Days
Total Wet Pounds x 1000	403.9	439.8	376.1
Wet Tons	201.9	219.9	188.0
Dry Tons	35.7	38.2	33.8
Volatile Tons	21.9	23.6	20.7
Percent Moisture	82.2	82.5	82.0
Percent Volatiles	61.9	62.5	61.4
Moisture/Volatile Ratio	7.70	7.87	7.58
Fuel (Natural Gas Equivalent) Used (1000 Cu. Ft.)	399.3	449.0	360.9
Standby Fuel Used (1000 Cu. Ft.)	155.3	0	155.3
Specific Fuel Consumption			
1000 ft^3 of Gas Equivalent/Wet Ton	2.63	2.19	2.97
1000 ft^3 of Gas Equivalent/Dry Ton	15.3	13.1	16.9
Number of Days	800	349 (43.6%)	451 (56.4%)

TABLE 4. BASELINE PERIOD DAILY AVERAGE VALUES BY MONTH

Month	Total Wet Pounds x 1000	Wet Tons Per Day	Dry Tons Per Day	Vol Tons Per Day	% H_2O	% Vol	M/V Ratio	Incineration Gas Equivalent (1000 Cu Ft)	Standby Gas Equivalent (1000 Cu Ft)	SFC Wet (1000 Cu Ft/ Wet Ton)	SFC Dry (1000 Cu Ft/ Dry Ton)
January	348	174	29	19	83	66	7.6	340	44	2.12	12.8
February	464	232	42	27	82	64	7.3	376	84	1.73	10.1
March	340	170	34	21	80	63	6.4	298	73	2.01	10.4
April	361	180	38	23	79	62	6.2	241	61	1.56	7.5
May	397	199	38	22	81	58	7.5	310	88	1.59	8.5
June	409	205	36	22	83	62	7.9	411	57	2.08	12.1
July	439	220	37	22	83	60	8.4	431	99	1.94	11.9
August	456	228	39	23	83	59	8.3	507	135	2.20	12.9
September	448	224	37	23	83	63	8.3	463	141	2.12	13.0
October	542	271	38	25	82	66	9.0	652	52	2.47	17.6
November	393	196	32	18	84	59	9.1	556	102	3.30	20.4
December	398	199	32	21	84	62	8.6	517	137	2.67	16.8

is discussed in later sections. The monthly averages basically showed the winter months to be characterized by higher sludge cake moisture levels, lower volatile levels, higher moisture to volatile ratios and, correspondingly, higher specific fuel consumptions. It is important to note at this point that the month of November historically had the highest sludge cake moisture to volatile ratios and the highest specific fuel consumption. As discussed later, the demonstration test was also conducted during the month of November in 1980 which provided a more critical test of the new operating mode for the Nashville operations.

ANALYTICAL PREDICTION OF REDUCED FUEL CONSUMPTION

An incinerator fuel prediction analytical model was employed to predict the lowest possible, or potential, fuel consumption obtainable by optimum incinerator operation. This model was developed by ICFAR from work done on the Indianapolis incinerator operations. The model predicts incinerator fuel requirements on the basis of completing all incineration processes including sludge cake drying, combustion, and ash cool-down in the available incinerator volume. The model is kinetic and it calculates, integrates, and iterates on gas temperatures, composition, and heat transfer rates which vary throughout the incinerator to arrive at a process-rate-determined solution. Energy balances are accomplished as only a first step in the solution.

The analytically predicted optimum specific fuel consumption (SFC) for the Nashville incinerators at given sludge cake moisture and loading rates is shown in Figure 5. The results assume complete use of the heated rabble arm cooling air which was not possible on the Nashville incinerators except at very high incinerator loading rates. A typical correction for the wasting of the rabble arm cooling air is also shown in Figure 5. The results show (1) increasing specific fuel consumption with increasing load and (2) increasing fuel consumption with sludge water content as would be expected. The analysis also shows that a moisture content of 75% with a 60% volatile cake would give a moisture to volatile ratio of M/V = 5 and autogenous combustion at reasonable operating sludge loads.

The kinetic results of Figure 5 may also be compared with the results obtained from assessment of the experimental airflow results, discussed in a previous section. Using typical conditions of 7 wet ton/hr, 82% moisture, and 60% volatile, the following results are obtained:

- Baseline fuel consumption = 12.5×10^3 ft^3 of gas/dry ton (from the baseline statistical analysis)
- Predicted new-mode fuel consumption based on assessment of experimental data = 7.5×10^3 ft^3 of gas/dry ton (40% less than baseline)
- Predicted new-mode fuel consumption based on kinetic analysis (Figure 5) = 7.0×10^3 ft^3 of gas/dry ton (44% less than baseline)

The predicted fuel reduction from both the experimental and analytical assessments were in close agreement.

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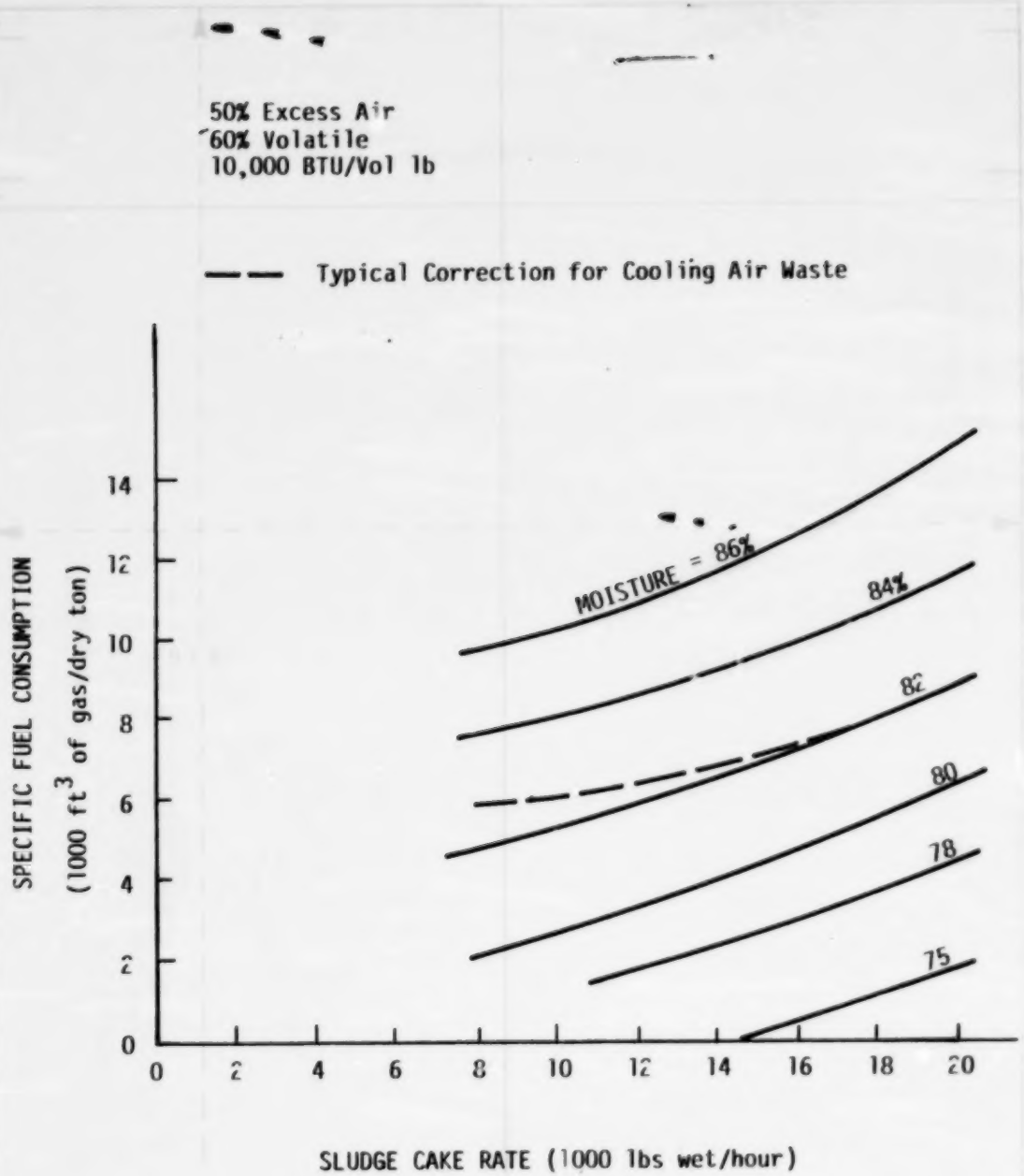


Figure 5. Incinerator Fuel Consumption Predicted by Kinetic Analysis

The kinetic analysis also helped determine the optimum standby operating mode. The two options were:

(1) Operate one incinerator at 15,000 lb/hr (average standby incineration rate) and have the other incinerator on standby.
(2) Operate two incinerators at 7,500 lb/hr with no standby.

Figure 5 indicates that the second choice was the most efficient.

The kinetic analysis provided information on the effect of burning level on fuel consumption. Results shown in Figure 6 indicate the predicted fuel decrease resulting from lower sludge combustion zones because of the increased sludge drying area associated with lower sludge combustion levels.

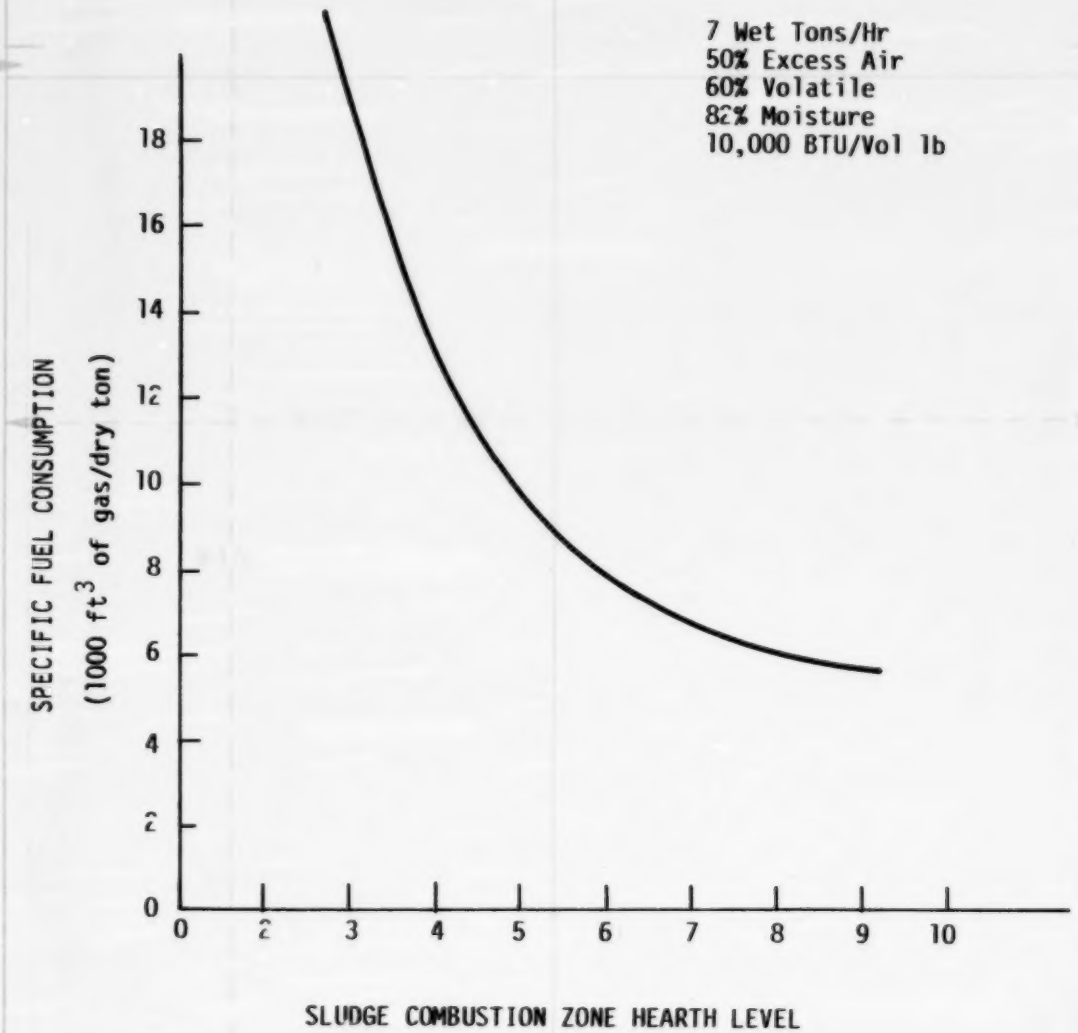


Figure 6. Effect of Combustion Level on Fuel Consumption (Kinetic Analysis)

SECTION 6

NEW INCINERATOR OPERATING MODE

A new operating mode was developed by ICFAR in consultation with Nashville officials. The new operating mode was derived from ICFAR's experience from the Indianapolis operations and from the combustion engineering analysis of the measurements made on the Nashville operations previously discussed. A preliminary set of specific operating instructions was prepared to teach the new mode to the incinerator operators and to conduct trial tests prior to the one month demonstration test. After completing the one month demonstration test, the operating mode instructions were further refined for both full operational and standby operational modes. The final operating mode instructions were not significantly different from the preliminary procedures recommended. They differed only in the respect that the final mode had more specific instructions for various loading rate conditions. Both the preliminary and final operating mode instructions are presented in the following sections.

FULL OPERATIONAL MODE

The new full operational mode was characterized by the following principal operating procedures:

- Slow centershaft speed to increase sludge drying area
- Maximum cooling air use to minimize hot air heat loss
- Replacement of cold auxiliary air by heated rabble arm cooling air return
- Low top draft to minimize top hearth air leakage
- Low excess air to minimize excess air heat loss
- Sludge combustion on hearth 7 to maximize sludge drying area
- Use of "low" hearth level burners to maximize drying temperatures
- Elimination of airflow to top burners to maximize drying temperatures
- Slight reduction in firing burner airflows to increase heated rabble arm cooling air use
- Underfire and overfire burner utilization to control maximum temperature and clinker formation.

The preliminary operating instructions given to the Nashville operators are shown in Figures 7 through 15.

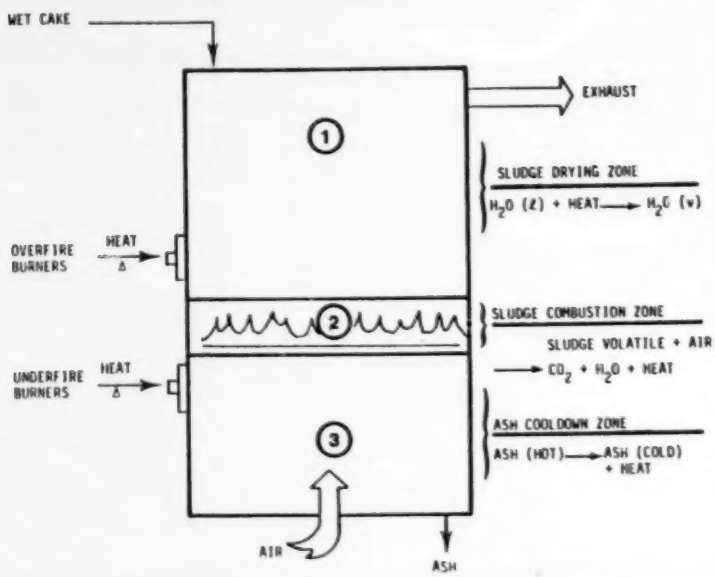


Figure 7. Overall Incineration Process

INCINERATOR CONTROL

ITEM	CONTROLLED BY
SLUDGE LOAD	FILTER OPERATOR
1 HEARTH DRAFT	EXHAUST SYSTEM DAMPER SETTINGS (ID FAN INLET)
EXHAUST OXYGEN (EXCESS AIR)	AIR ENTRY DAMPER SETTINGS: • COOLING AIR RETURN DAMPER • AUXILIARY AIR DAMPER
SLUDGE COMBUSTION LEVEL	FUEL FLOW (BURNER FIRING RATE)
FUEL FLOW	NUMBER OF BURNERS "ON" AND FIRING RATE • MANUAL 3 PSI = MIN. FIRE; 15 PSI = MAX. FIRE • AUTOMATIC ACTUAL VS SET POINT TEMPERATURE
MAXIMUM TEMPERATURE (CLINKERING)	• UNDERFIRE* BURNER FIRING RATE • EXHAUST OXYGEN (EXCESS AIR) • COOLING AIR UTILIZATION

*BELOW SLUDGE COMBUSTION LEVEL

Figure 8. Incinerator Control

1. MAINTAIN STEADY LOAD

2. MAINTAIN DRAFT OF .02 - .04 IN WATER ON 1 HEARTH

3. MAINTAIN 3 - 4% EXHAUST OXYGEN (WET BASIS; 5 - 6% DRY BASIS)

4. MAINTAIN SLUDGE COMBUSTION ON 7 HEARTH

5a. MAXIMIZE USE OF "LOW" BURNERS

5b. LIMIT MAXIMUM TEMPERATURE TO 1550°F TO PREVENT CLINKERS

Figure 9. General Operating Procedure

FEED RATE - STEADY; SET TO AVOID NEED FOR STANDBY, IF POSSIBLE.

CENTER SHAFT - SET TO 0.70 RPM. INCREASE SPEED ONLY IF REQUIRED TO KEEP SLUDGE LEVEL BELOW RABBLE ARMS.

COOLING AIR - RETURN TO 10 HEARTH ONLY. VARY AS REQUIRED TO CONTROL EXHAUST OXYGEN TO 3 - 4% (WET).

AUXILIARY AIR - FAN GENERALLY OFF. ENTER ON 10 HEARTH ONLY IF MORE AIR IS REQUIRED THAN IS AVAILABLE FROM COOLING RETURN.

DOORS/PEEPS/LANCE HOLES - CLOSED TIGHT ON ALL LEVELS.

BURNERS - ADJUST OVERALL FIRING RATE TO BURN SLUDGE ON 7 HEARTH.

- USE LOWEST POSSIBLE BURNERS.
- ADJUST UNDERFIRE BURNER FIRING RATE TO MAINTAIN 1550° MAX. TEMPERATURE TO AVOID CLINKERS.
- NEVER USE 2 HEARTH BURNERS; SHUT OFF 2 HEARTH BURNER AIR.
- GENERALLY DO NOT USE 4 HEARTH BURNERS; SHUT OFF 4 HEARTH BURNER AIR IF DOWN FOR EXTENDED TIME.
- DETERMINE TEMPERATURE PROFILE MANUALLY, THEN SET BURNERS TO AUTOMATIC IF DESIRED.

Figure 10. Specific Settings for Normal Operation

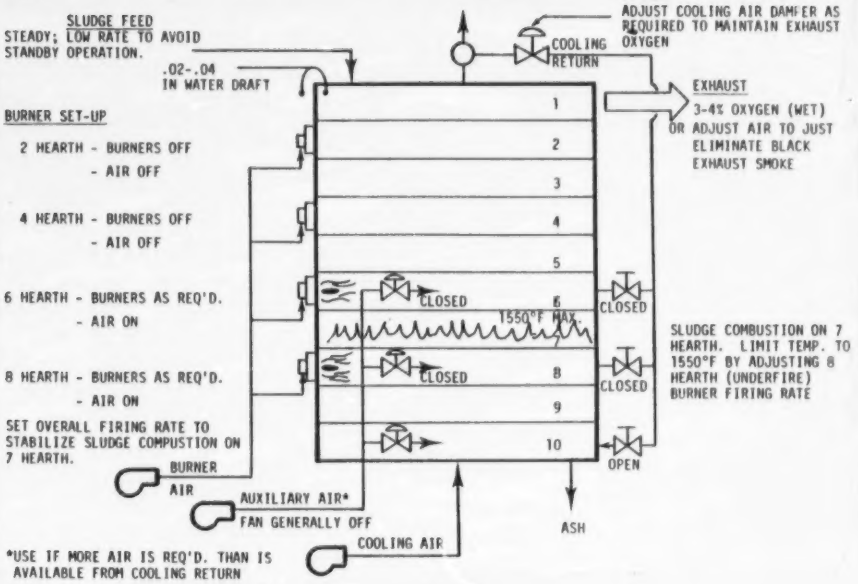


Figure 11. Summary of Optimum Operation

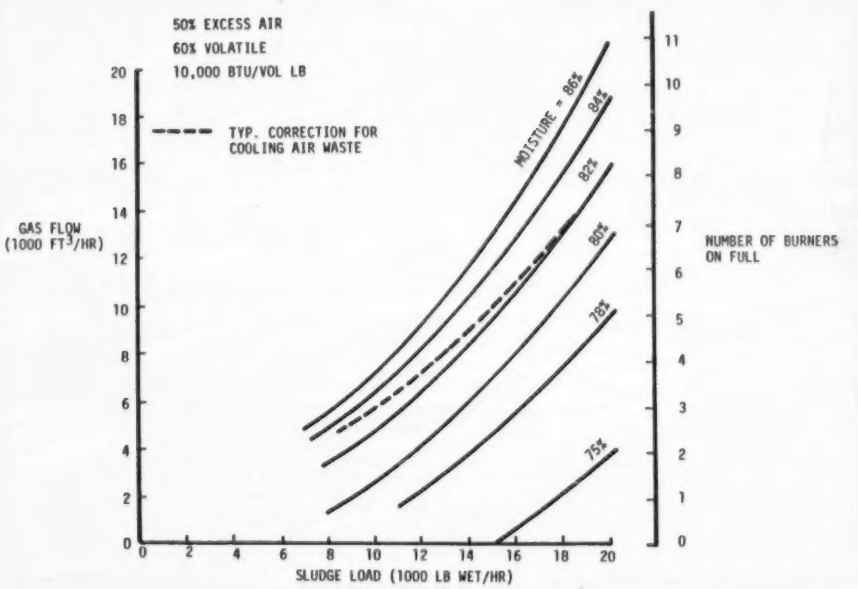


Figure 12. Fuel Flow Guideline

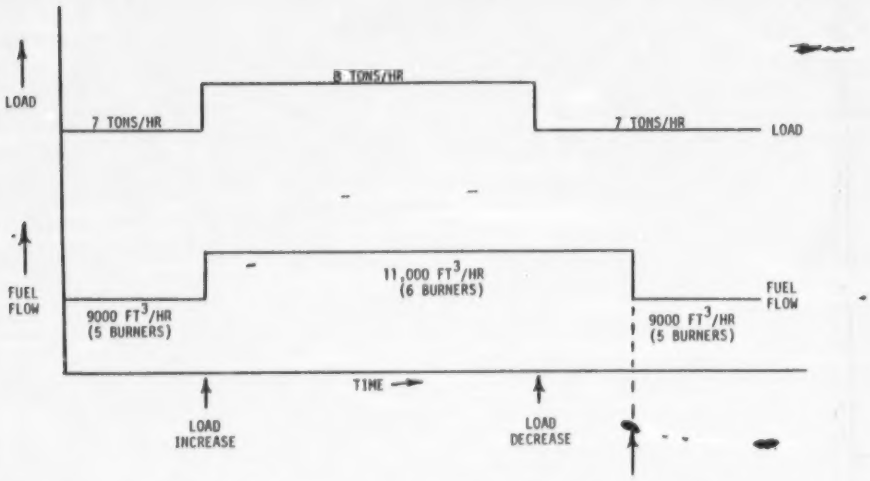


Figure 13. Unsteady Load Procedures

CAUSE: INSUFFICIENT SLUDGE DRYING RATE RELATIVE TO FEED RATE

REMEDIES: (1) INCREASE BURNER FIRING RATE AND/OR

(2) REDUCE FEED RATE

MILD DROP (FIRE ON 8 HEARTH) - (1) INCREASE BURNER FIRING RATE BY APPROXIMATELY 25%

(2) REDUCE FIRING RATE AS FIRE CLIMBS TO 7 HEARTH

SEVERE DROP (FIRE ON 9 HEARTH) - (1) INCREASE FIRING RATE BY 50 - 100%

(2) REDUCE SHAFT SPEED TO 0.50 RPM IF POSSIBLE

(3) REDUCE SLUDGE FEED RATE

(4) RETURN TO STABLE CONDITION AS FIRE CLIMBS

LOST IT (SLUDGE IN BSMT.) - (1) STOP FEED

(2) CLEAR INCINERATOR

(3) RE-ESTABLISH FEED

(4) WORK TO STABLE CONDITION

Figure 14. Procedures for Dropping Combustion Zone

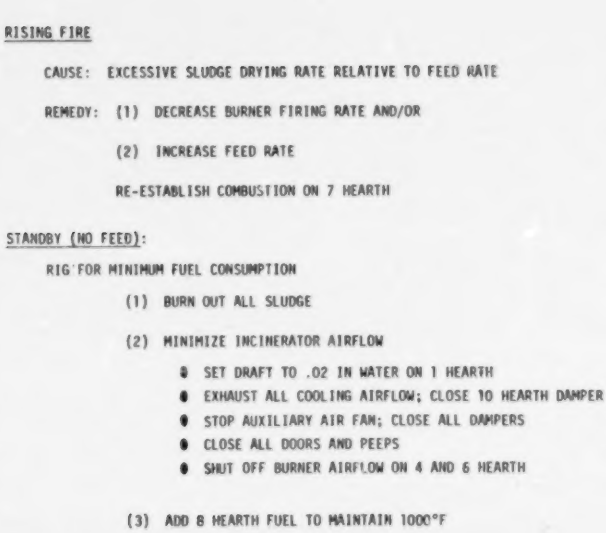

RISING FIRE
CAUSE: EXCESSIVE SLUDGE DRYING RATE RELATIVE TO FEED RATE
REMEDY: (1) DECREASE BURNER FIRING RATE AND/OR
(2) INCREASE FEED RATE
RE-ESTABLISH COMBUSTION ON 7 HEARTH
STANDBY (NO FEED):
RIG FOR MINIMUM FUEL CONSUMPTION
(1) BURN OUT ALL SLUDGE
(2) MINIMIZE INCINERATOR AIRFLOW
SET DRAFT TO .02 IN WATER ON 1 HEARTH
EXHAUST ALL COOLING AIRFLOW; CLOSE 10 HEARTH DAMPER
STOP AUXILIARY AIR FAN; CLOSE ALL DAMPERS
CLOSE ALL DOORS AND PEEPS
SHUT OFF BURNER AIRFLOW ON 4 AND 6 HEARTH
(3) ADD 8 HEARTH FUEL TO MAINTAIN 1000°F

Figure 15. Procedures for Rising Combustion Zone and Standby Operation

The final operating instructions with load rate specifications are summarized in Figure 16. This mode was the most optimum for Nashville and also encompassed a new sludge load management operating procedure to minimize standby fuel use. Previous operational practice was to run both incinerators at high loading rates until the sludge inventory was reduced. Then, one incinerator was operated with the other placed in a standby mode at 1000°F. This practice was followed because past experience had shown higher fuel use when the incinerators were operated at low loading rates. With the new operating mode techniques, however, the incinerators could be operated more efficiently at load rates one half the design rate with no problem, thus enabling the load to be split between the two incinerators at all times making it possible to maintain and keep up with the incoming sludge load. This approach enabled Nashville to realize fuel savings both in more efficient incineration and in the reduction of standby fuel use as will be discussed in Section 7. An average incinerator load rate of 8,400 lbs per hour per incinerator was recommended as a target rate to "keep up" with the incoming sludge load based on past operational averages.

The full operational mode procedures in summary are:

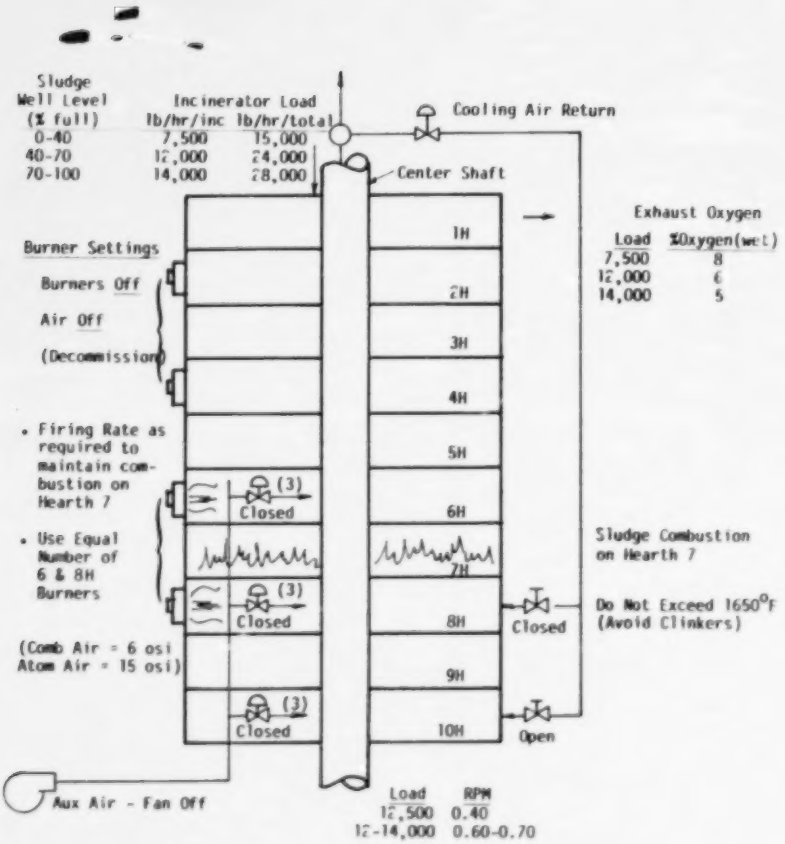
- Operate with optimum excess air to minimize emissions and incinerator fuel consumption.
- Eliminate the use of burners on hearths 2 and 4 because they did not provide efficient drying.
- Use hearth 6 and 8 burners only because they provide more efficient drying
- Sludge combustion should be on hearth 7 to maximize sludge drying area.
- Use rabble arm cooling air return instead of auxiliary air to capture the heated air energy.
- Use slow rabble arm shaft speeds to obtain most efficient sludge drying

STANDBY OPERATIONAL MODE

The standby operational mode was characterized by minimum airflow through the incinerator to minimize fuel required to accomplish 1000°F temperature on hearth 7 and 8:

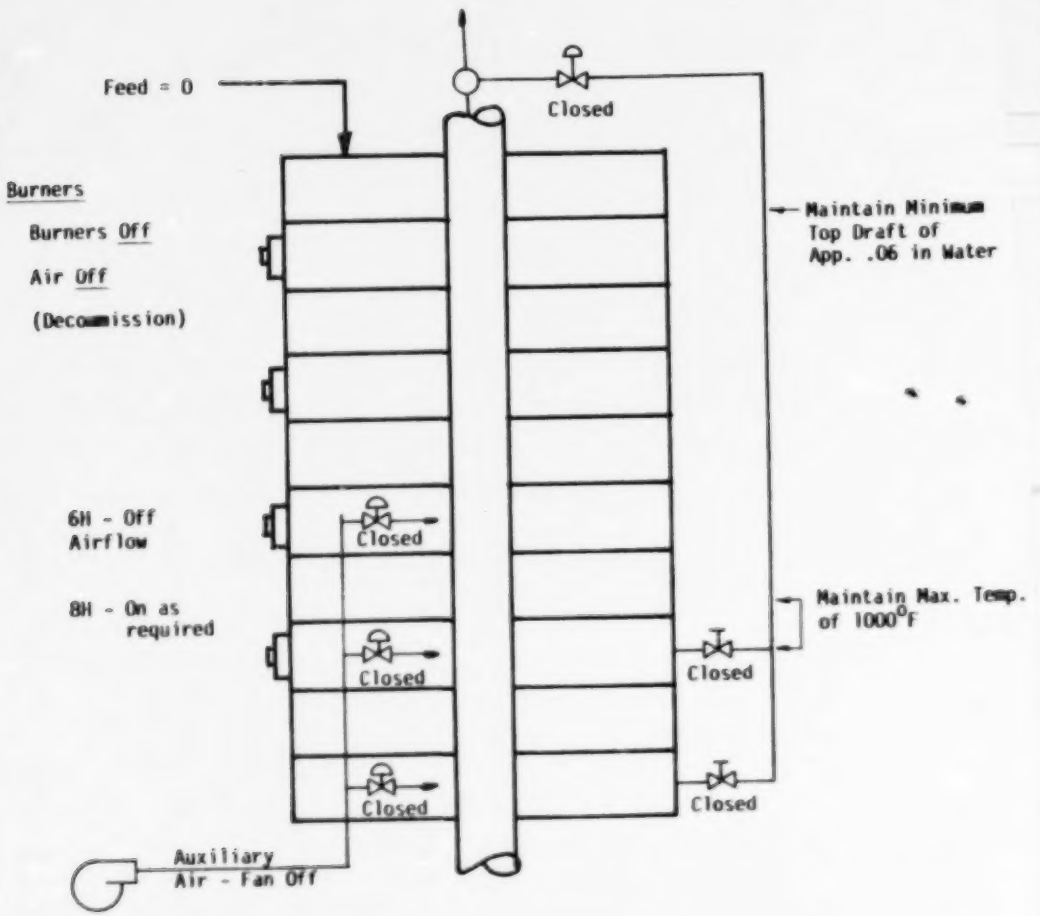
- Minimum top draft
- Waste rabble arm cooling air
- No auxiliary air
- All openings closed
- Shut off air on burners not in use

The recommended standby operating mode is summarized in Figure 15 and 17. Both short and extended standby periods could be needed at various times. The short standby procedure applies to approximately the first 3 hours of a load interruption. This mode involves shutting off most burners at once and varying center shaft speed to maintain sludge combustion on hearth 7.



Notes:
1. Run loads less than 20000 lbs/hr total with 1 filter & 2 incinerators
2. Top draft app. .06-.08 in water (just enough to stop room smoke)
3. Control exhaust oxygen with cooling air return
4. Control sludge burn level with burner firing rate
5. Reduce max. temp. by using burners above sludge combustion level. Add air at combustion zone only if necessary.

Figure 16. Recommended Full Operational Mode



Short Term

1. Shut-Off all burners except one on Hearth 8 (low fire)
2. Progressively reduce center shaft RPM to maintain sludge burning on Hearth 7
3. Maintain approximately 8% oxygen level

Extended Term

4. After combustion of all sludge, light Hearth 8 burners as required to hold 1000°F max. temp.
5. Incinerator configuration on extended standby

Figure 17. Recommended Standby Operating Mode

After all the sludge is burned, extended standby would be started to maintain 1000°F on hearth 7 with minimum fuel flow. This is accomplished by minimizing incinerator airflow through the following measures:

- Minimum draft as required to prevent room smoke.
- Close cooling air return damper on hearths 6, 8, and 10.
- Shut off auxiliary air fan. Close all dampers.
- Shut off air on all burners except hearth 8.

This operating mode will maintain 1000°F with approximately two to three hearth 8 burners versus the previous experience of needing four to six burners.

OTHER OPERATIONAL FACTORS

Load Rate Effect

The selected incinerator loading rate has a large effect on fuel consumption as shown in Figure 18. The Nashville operation has considerable flexibility in load selection because of the excess capacity represented by the two 10 hearth incinerators. These incinerators are rated at 20,000 lb/hr each for a total capacity of 40,000 lb/hr. The baseline period statistical analysis showed that the average sludge load is only 8,400 lb/hr per incinerator. Some incinerator "down" time must be expected. With a reasonable 30% "down" time, an average incinerator load of only 12,000 lb/hr/incinerator is required to "keep up". The incinerator load schedule recommended is shown in Table 5. The recommended incinerator load would vary as a function of sludge well level. The intent of this recommendation was to completely eliminate standby operation and excessively high incinerator loadings, both of which increase fuel consumption tremendously. Expected fuel reduction from implementing the Table 5 load schedule (and nothing else) would be 25%.

The constant goal in incinerator operation should be to achieve steady operation to reduce fuel consumption and operating effort. A prerequisite for steady incinerator operations is a constant sludge feed rate. With constant sludge rate established, the incinerator can be set up for steady operation in approximately 1.5 hours. Figure 19 shows an example of a strip chart record for a constant steady-temperature operation.

TABLE 5. RECOMMENDED NASHVILLE INCINERATOR LOADING

Sludge Well Level	Sludge Load lb/hr/inc.	Sludge Load lb/hr-total
0-40% Full	7,500	15,000
40-70% Full	12,000	24,000
70-100% Full	14,000	28,000

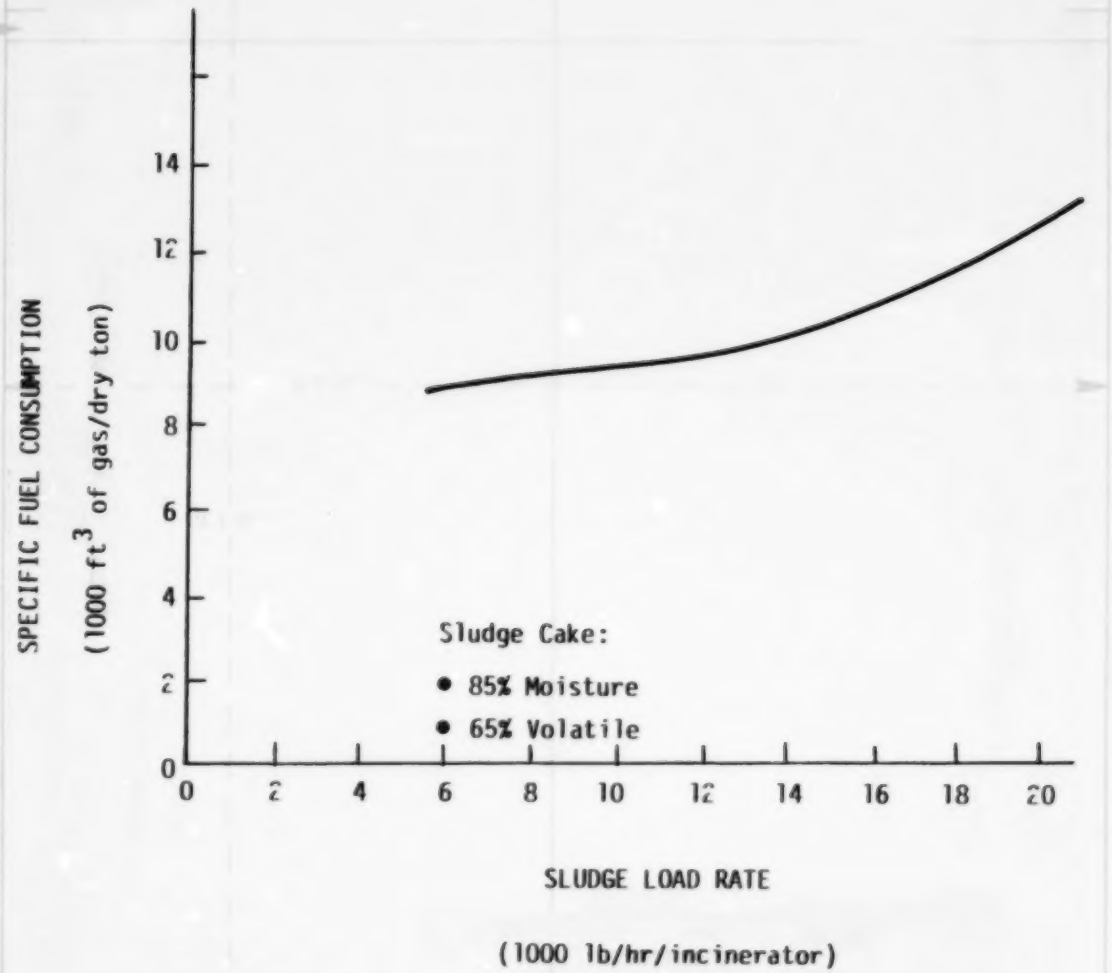


Figure 18. Effect of Load Rate on Specific Fuel Consumption

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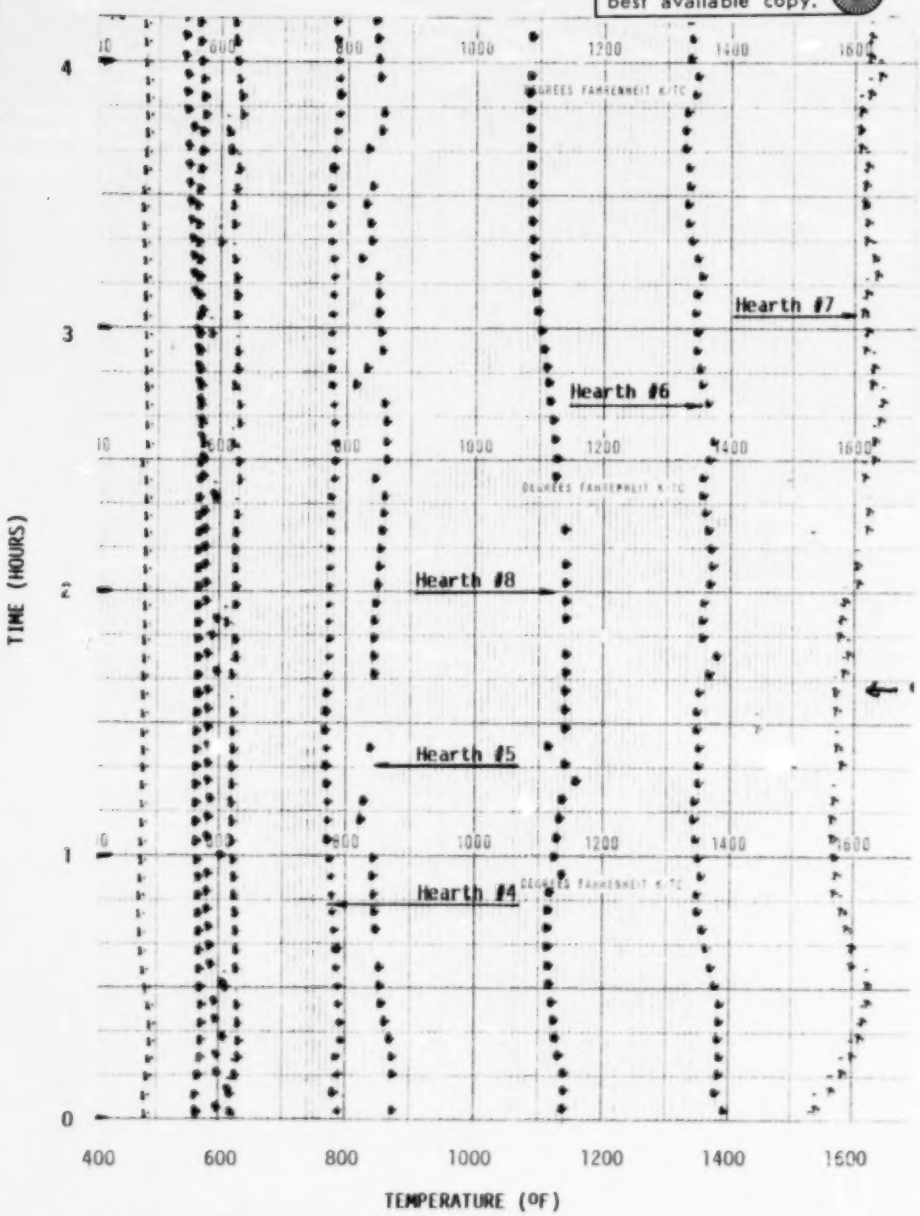

Figure 19. Example of Steady Temperature Operation

Effect of Operational Upsets

A sudden incinerator load increase or decrease is an upset that can severely affect performance. A sudden load increase can drop the combustion level to lower hearths. There was initially some operator concern that such an upset could be enough to cause loss of fire when operating in the new mode with the combustion zone on hearth 7. Conversely, a sudden load decrease can result in a rising fire and excessively high temperatures (incinerator burnout).

Incinerator operation can be controlled during feed upsets by monitoring hearth temperatures and taking appropriate action. For example, an overload is indicated by dropping temperatures which calls for a burner firing rate increase. An underload is indicated by increasing temperatures which calls for a burner firing rate decrease. By prompt action, severe operational upsets can generally be avoided.

Oxygen Analysis

Oxygen analysis of the exhaust gas is necessary for optimum incinerator operation. As previously discussed, insufficient air at the combustion zone produces exhaust smoke. It also increases fuel consumption by inhibiting full heat release from the sludge and auxiliary fuel. Insufficient air supply can actually prevent temperature increase in spite of huge fuel additions.

Excessive combustion zone air is also a heat loss which increases fuel consumption. The correct air level can be visually established by a skilled operator. However, the operator would have to be at the combustion level almost full time to monitor conditions in this manner because the excess air level can change drastically in minutes as a result of the changing load rates, burning levels, burner firing rates, or sludge cake characteristics. In view of these constantly-varying factors, there is no effective substitute for exhaust oxygen analysis and it should be displayed and recorded in the control room.

The incinerator exhaust oxygen serves as an operational guide only. The optimum oxygen level cannot be specified exactly because the excess air level at the combustion zone will be significantly less than at the exhaust as a result of incinerator air leakage in the upper hearths. Furthermore, the air leakage as a percentage of combustion air will vary with the load even though the absolute air leakage might be constant. Another complication is the oxygen dilution by the sludge cake water which varies with moisture content. Due to all these factors, the operator must correlate indicated oxygen with visual observation to establish exact incinerator oxygen level. The required oxygen level will generally vary with load rate. The oxygen values given in Table 6 are recommended.

Shaft Speed

The shaft speed (rpm) should be selected to achieve the lowest fuel consumption. This will be obtained at the shaft speed providing the best

sludge drying performance. At fast shaft speeds, sludge cake drying performance is reduced because the sludge cake drying area is a minimum (equal to hearth area). With very slow shaft speeds, the sludge cake surface can dry out ("crust"), thereby, impeding the drying performance. The optimum shaft speed is, therefore, intermediately-slow enough to form good sludge "furrows" which increase drying area, yet fast enough to result in no significant crusting in the upper hearths. The optimum shaft speed will vary with sludge cake load. The shaft speeds recommended for operational use are summarized in Table 7.

The center-shaft speed control has been used in the past to control the sludge burning level. A shaft speed increase might be used to drop the sludge burning level to the desired hearth. However, the burning level established in this manner is not stable because the shaft speed increase only provides a temporary internal load increase which disappears in 1-2 hours as the hearth sludge levels adjust to the higher speed. Then, the sludge combustion level can be expected to climb again. Rather than going through these center shaft transients, the burning level should be adjusted with the burner firing rate. Center shaft speed should be held constant during normal operation. Center shaft speed variation should only be employed to combat emergencies such as loss of fire or burnout.

Clinker Formation

Clinker formation is primarily the result of excessive temperature which causes the ash to fuse. A contributing factor can also be the rabbling pattern of the rabble arms that leaves a portion of a hearth "unswept". Clinkers could slowly build in such an area. Experience has shown that a temperature limit of 1650°F can be tolerated without clinkering.

TABLE 6. OPTIMUM EXHAUST OXYGEN VALUES

Sludge Cake Load (lb/hour)	Exhaust Oxygen (% Volume, Wet Basis)
8,000	8
10,000	7
12,000	6
14,000	5

TABLE 7. CENTER SHAFT SPEED GUIDELINES

Sludge Cake Load (lb/hour)	Center Shaft Speed (rpm)
8,000	0.40
12-14,000	0.60-0.70

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SECTION 7

FUEL REDUCTION RESULTS

DEMONSTRATION TEST RESULTS

The incinerator operating modes developed were evaluated during a 28 day Demonstration Test conducted November 2 through November 29, 1980, on-site in Nashville. Both full and standy operational modes were evaluated.

Full Operational Mode Test Results

The full operational mode Demonstration Test was conducted for a 26 day period from November 2 through November 27, 1980. The two incinerators were generally fully operational during this period. Natural gas auxiliary fuel was exclusively used.

It was mutually agreed to target the Demonstration Test for 12,000 wet lb/hr/incinerator. This load rate was 36% higher than the average November baseline period full operational mode load of 8,800 lb/hr/incinerator. The 12,000 lb/hr load was kept as a target rate through November 15, 1980. Starting November 16, 1980 the mutually-agreed target load was increased to 14,000 wet lb/hr/incinerator to reduce the sludge well level.

The incinerators were operated in accordance with the full-efficient operating modes previously discussed. Slight procedural changes were found necessary during the Demonstration Test. Eleven of the test days had gross variations in the hourly load rate. For two days, November 24 and 25, the sludge inventory had been reduced to a level that precluded full operation because the prescribed target load rate had been increased to prove that running two incinerators above the target rate would cause a standby condition.

The Demonstration Test daily fuel consumption, load and sludge cake composition results are shown in Table 8. The results were obtained from the standard Nashville daily operational records.

The percent fuel reduction, PFR_o, for the full operational mode was determined as follows:

$$PFR_o = \frac{A - a}{A} \times 100\%$$

where:

TABLE 8. FULL OPERATIONAL MODE DEMONSTRATION TEST RESULTS-DAILY AVERAGES

Date	FUEL USE Ft^3 of Gas	SLUDGE CAKE Weight (wet lb)	Moisture (%)	Volatile (%)	M/V Ratio	Specific Fuel Consumption (ft^3/dry ton)
11-2-80	155,200**	300,700(2)	85.3	68.2	8.50	7,022
11-3	116,700**	280,000(2)	83.1	68.4	7.19	4,932
11-4*	290,000	491,600	85.0	68.5	8.27	7,865
11-5*	300,000	465,400	85.7	68.3	8.74	9,193
11-6	270,000	550,800	85.8	69.4	8.67	6,880
11-7	310,000	562,600	85.2	66.8	8.61	7,446
11-8	290,000	542,300	85.6	64.8	9.17	7,427
11-9	320,000	512,650	85.9	63.8	9.55	8,854
11-10	280,000	528,100	86.0	65.3	9.45	7,601
11-11	320,000	512,600	86.1	65.2	9.50	8,982
11-12*	310,000	455,850	85.9	66.8	9.88	10,382
11-13*	320,000	490,600	87.0	66.1	10.12	10,035
11-14	280,000	528,350	85.8	65.5	9.23	7,454
11-15	210,000	520,700	86.1	64.9	9.53	5,803
11-16	230,000	462,200	85.9	67.2	9.02	7,003
11-17*	300,000	425,900	87.0	66.4	10.12	10,921
11-18*	370,000	522,100	86.4	65.7	9.67	10,422
11-19*	360,000	580,100	85.4	68.5	8.53	8,501
11-20*	370,000	581,200	84.8	68.7	8.12	8,376
11-21	230,000	591,900	85.6	66.6	8.92	5,397
11-22*	240,000	275,200	83.2	69.4	7.14	10,382
11-23	240,000	535,300	83.8	67.3	7.69	5,535
11-24	Low Sludge Inventory					
11-25	Low Sludge Inventory					
11-26	260,000	465,900	85.2	67.4	8.54	7,541
11-27	280,000	548,200	86.4	67.1	9.46	7,511
			AVERAGE		8.90	7,979

*Days with gross hourly variations in load rate
**One incinerator on standby

A = Baseline full operational mode specific fuel consumption corrected for sludge cake M/V ratio
a = Demonstration Test full operational mode specific fuel consumption

The baseline period (January 1, 1978 through May 31, 1980) specific fuel consumption was related to sludge cake moisture/volatile weight ratio. This relationship, as previously discussed in Section 5 is shown again in Figure 20 and is described by the following least-squares straight line equation:

$$A = 2.55 \frac{M}{V} - 7.7 \ (\times 1000)$$

where:

A = Baseline period full operational mode specific fuel consumption (1000 ft^3 gas/dry ton)
$\frac{M}{V}$ = Sludge cake moisture/volatile ratio (lb/lb)

As shown in Table 8, the average daily specific fuel consumption was 7,979 ft^3 of gas per dry ton. The average daily sludge cake M/V ratio was 8.9. For comparison, the baseline specific fuel consumption (SFC_B) for the average sludge cake M/V of 8.9 was:

$$SFC_B = 2.55 \left(\frac{M}{V}\right)_D - 7.7 \ (\times 1000)$$

$$= 2.55 \ (8.9) - 7.7 = 14{,}995 \ ft^3/\text{dry ton}$$

Using these average values the full operational mode demonstration test percent fuel reduction (PFR_o) was:

$$PFR_o = \frac{A - a}{A} \times 100\%$$

$$= \frac{14{,}995 - 7{,}979 \ ft^3/\text{dry/ton}}{14{,}995 \ ft^3/\text{dry ton}} \times 100\%$$

$$PFR_o = 46.8\%$$

Figure 20 also shows the average specific fuel consumption and M/V ratio for the demonstration test period for comparison.

Standby Operational Mode Test Results

As discussed previously, the Nashville operations had a large number of standby mode days. Auxiliary fuel is used in the standby mode to keep at least one incinerator hot without burning sludge until ready to receive sludge. The standby mode was also used when it was judged that the sludge

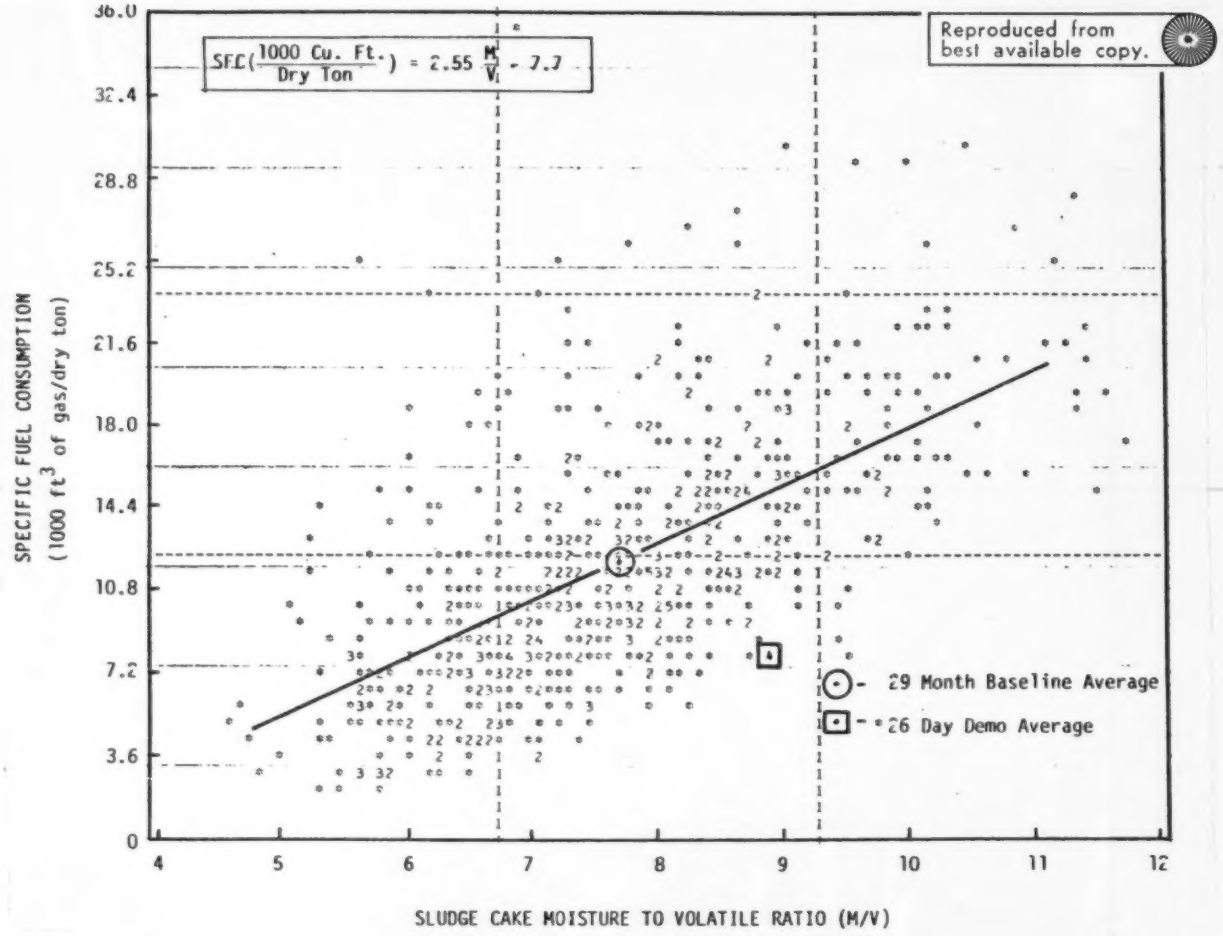

Figure 20. Specific Fuel Consumption for Baseline Period Operations

well had insufficient sludge to warrant operating both incinerators or when breakdowns occurred.

Two Standby Mode options were considered for the Demonstration Test. The first option was to send all the sludge load to one incinerator while maintaining the second on standby. This was the procedure normally employed in the past by Nashville. The second option was to send half of the total sludge to each incinerator, thereby eliminating standby entirely as was discussed previously as being the most fuel-efficient option. Figure 21 shows the predicted decrease in operational fuel consumption from using two incinerators instead of one. Complete elimination of standby would further reduce fuel use. The estimated baseline fuel reduction resulting from elimination of standby is shown in Figure 22.

The full-efficient standby mode was to be evaluated during five 8-hour tests with one test conducted per day. By mutual agreement, the standby Demonstration period was increased to six 8-hour tests conducted back-to-back on November 28 and 29, 1980. This allowed the use of normal Nashville daily fuel consumption records and minimized setup time. The target total sludge load was 15,000 wet lb/hr by mutual agreement. This load rate of 180 wet tons per day was essentially the same as the 183.3 tons per day averaged during the baseline November standby mode days. All six 8-hour test periods were conducted without any operational problem with sludge load split between the two incinerators.

The standby mode Demonstration Test percent fuel reduction (PFR_{sb}) was determined as follows:

$$PFR_{sb} = \frac{(B - b) + (C - c)}{B + c} \times 100\%$$

where:

B = Baseline period daily average operational specific fuel consumption for Standby Mode days
b = Demonstration Test Standby Mode operational specific fuel consumption (fuel used for incineration)
C = Baseline period average standby specific fuel consumption for Standby Mode days
c = Demonstration Test standby specific fuel consumption

The results of the standby mode demonstration test are shown in Table 9. No standby fuel was used during the "standby" demonstration test since all fuel was used for incineration in the two operating incinerators. Then, to compute PFR_{sb} for the standby test the values were as follows:

(1) B = Baseline period daily average operational SFC

$$= [2.55 \left(\frac{M}{V}\right)_D - 7.7] \text{ (x 1000) ft}^3 \text{ of gas/dry ton}$$

$$= [2.55 (8.5) - 7.7] \text{ (x 1000)} = 13{,}975 \text{ ft}^3 \text{ of gas/dry ton}$$

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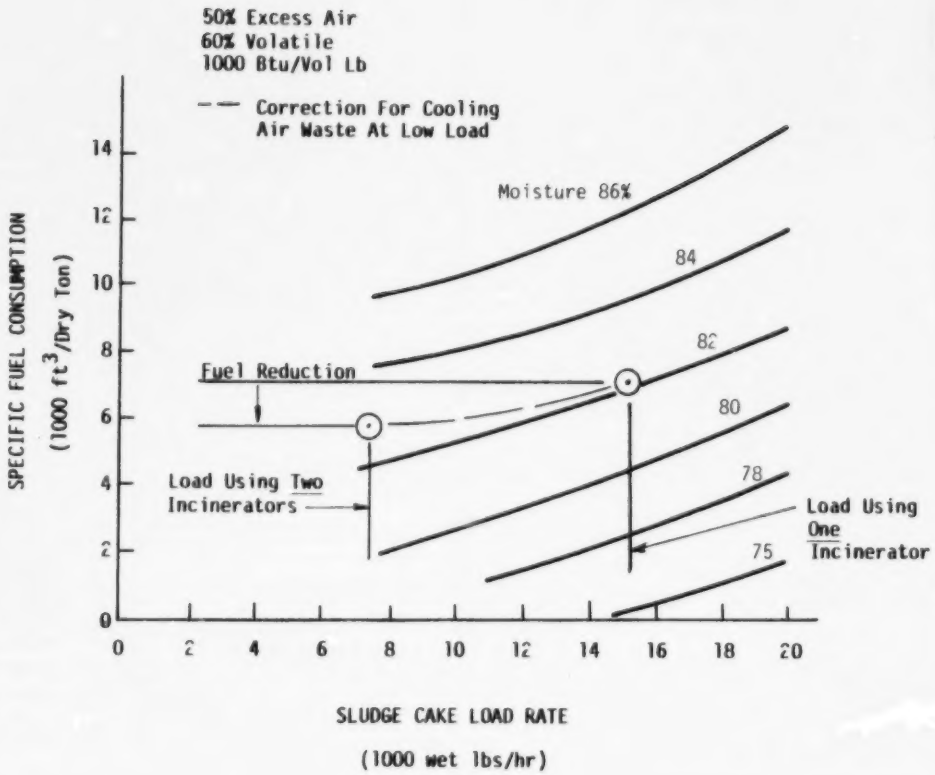

Figure 21. Operational Fuel Consumption Reduction Predicted for Using Two Incinerators During Standby Days

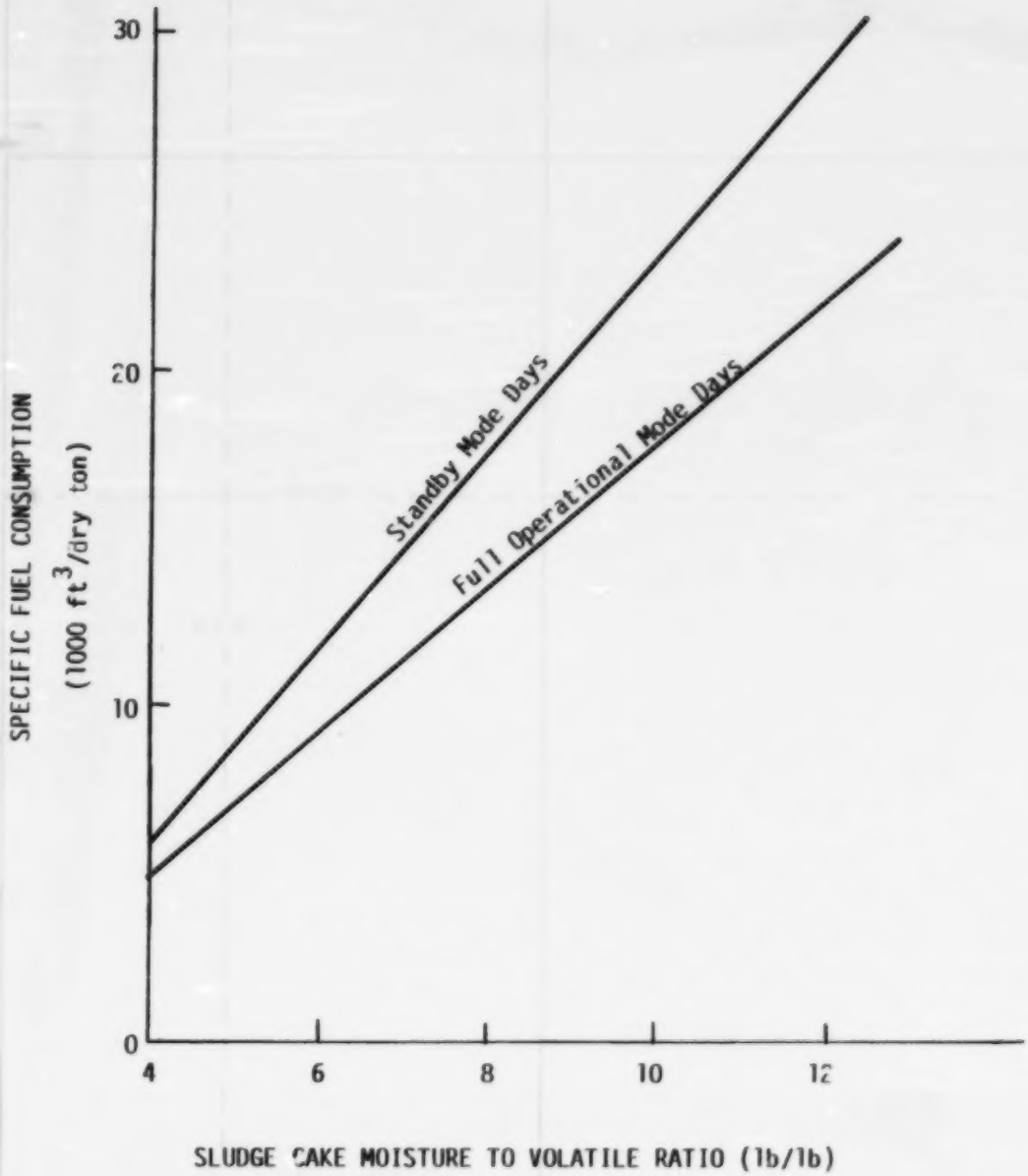

Figure 22. Estimated Baseline Fuel Reduction Resulting From Elimination of Standby Operations

(2) b = Standby test period average operational SFC
= 6,420 ft^3 of gas/dry ton (from Table 9)

(3) C = Baseline period average standby SFC for standby mode days
= 4,600 ft^3 of gas/dry ton

(4) c = Demonstration test standby SFC
= 0 since no standby fuel used

Then,

$$PFR_{sb} = \frac{(B - b) + (C - c)}{B + C} \times 100\%$$

$$= \frac{(13,975 - 6,420) + (4,600 - 0)}{13,975 + 6,420} \times 100\%$$

$$= \frac{12,155}{20,395} \times 100\%$$

$$PRF_{sb} = \underline{59.6\%}$$

Total Percent Fuel Reduction

The total percent fuel reduction demonstrated from the two operating mode fuel reductions relative to the historical baseline fuel consumptions for each mode was computed as follows

$$PFR_t = \frac{(PFR_o)E_o + (PRF)_{sb}E_{sb}}{E_o + E_{sb}} \times 100\%$$

TABLE 9. STANDBY MODE DEMONSTRATION TEST RESULTS

Date	Fuel Used* (Ft^3 of Gas)	Sludge Cake (Wet Lbs)	Sludge Cake (Dry Tons)	M/V Ratio
11-28-80	160,000	342,800	25.54	8.5
11-29-80	180,000	368,000	27.42	8.5
TOTAL	340,000	710,800	52.96	---

*Average Fuel Consumption = 6,420 ft^3 of gas/dry ton.

where:

PFR_o = Full operational mode PFR (decimal form)

PFR_{sb} = Standby operational mode PFR (decimal form)

E_o = Total baseline period fuel consumption for 349 full operational mode days (ft^3 of gas)

E_{sb} = Total baseline period fuel consumption for 451 Standby operational mode days (ft^3 of gas)

From Table 3,

$$E_o = 156,695,850 \text{ ft}^3 \text{ of gas}$$

$$E_{sb} = 232,805,320 \text{ ft}^3 \text{ of gas}$$

and with $PFR_o = 46.8\%$ and $PFR_{sb} = 59.6\%$, then:

$$PFR_t = \frac{(.468)156,695,850 + (.596)232,805,320}{156,695,850 + 232,805,320} \times 100\%$$

$$= \frac{73,333,658 + 138,751,971}{389,501,170} \times 100\%$$

$$PFR_t = \underline{54.5\%}$$

On an annual basis, this percent fuel reduction represented a potential fuel savings for Nashville of over 87 million cubic feet of gas per year, or a dollar savings of approximately $307,000 per year based on a gas price of $3.50 per thousand cubic feet. The fuel reduction achieved in routine operations for the ten months since the demonstration tests is presented in the next Section.

ROUTINE OPERATIONAL RESULTS

Incineration Fuel Reduction

The Nashville operational records for ten months of operation with the new operating mode were analyzed to determine the fuel reduction achieved in routine operations. Operating data for the period November, 1980 through August, 1981 were analyzed to compare specific fuel consumption results with those of the twenty-nine month baseline period.

Again, the principal measure used for comparison was the specific fuel consumption (SFC) on a dry ton of sludge cake basis. As discussed previously, an accurate comparison of fuel consumption must account for the moisture to volatile ratio (M/V) of the sludge cake being incinerated to avoid a distorted comparison. For this reason, the relationship of the daily average SFC and the sludge cake M/V ratio were computed for the ten month operating period and compared to the same relationship found for the baseline period.

A least squares regression analysis was made for the SFC versus sludge cake M/V ratios for both periods. The results of these analyses are shown in Figures 23 and 24 with the computed regression line drawn to reflect the overall change observed. Figure 25 shows both lines on one graph for comparison. Table 11 gives the averages of the other operational variables for the two time periods.

As shown in Figure 25, the average sludge cake M/V ratio for the ten month period was higher than the baseline period (12.7%) process changes that occurred between the two periods. The specific fuel consumption was reduced, as well as the basic relationship between SFC and sludge cake M/V ratio, as reflected by the decreased rate of increase of SFC with M/V ratio. At the low M/V ratio of 6, the computed SFC difference was 22.6 percent, and at the high M/V ratio of 10, the difference was 42 percent. Table 10 shows the computed difference in SFC for various sludge cake M/V ratios. The SFC difference corresponding to the average sludge cake M/V ratio for the ten month period (8.68) was 38.9 percent.

The 38.9 percent reduction as shown in Table 10 represented a fuel saving of 5,612 ft^3 of gas per dry ton of sludge cake incinerated. The total incineration fuel saving for the ten month period was:

Savings = 5,612 ft^3 of gas/dry ton x 35.8 dry tons/day x 297 days/10-month period

= 59,670,154 ft^3 of gas/10 months

This level of savings is approximately 5,976,015 ft^3 of gas per month, or 71,604,180 ft^3 per year. At gas prices of \$3.50/1000 ft^3, the cost savings is over \$250,000 per year for incineration fuel.

Standby Fuel Reduction

The operational records for the standby fuel used during the ten month period were also analyzed. Only the first seven months of the ten month November through August period could be used because pollution equipment operational testing was being conducted on the two older reserve incinerators making the data not typical for routine operations during the latter part of the period. The standby fuel use recorded during these seven months with the new mode and the standby fuel use for the same months in the previous year when the old operating mode was being used are shown in Table 12. The comparison showed a dramatic 75% reduction in standby fuel use. The average standby fuel savings of 2,300,000 ft^3 of gas per month represents an annual savings of 27,600,000 ft^3, and potential cost savings of over \$96,000 per year (at \$3.50/1000 ft^3) if this operational level is maintained.

The total combined fuel savings achieved by the Nashville operations using the new operating mode is approximately \$350,000 per year.

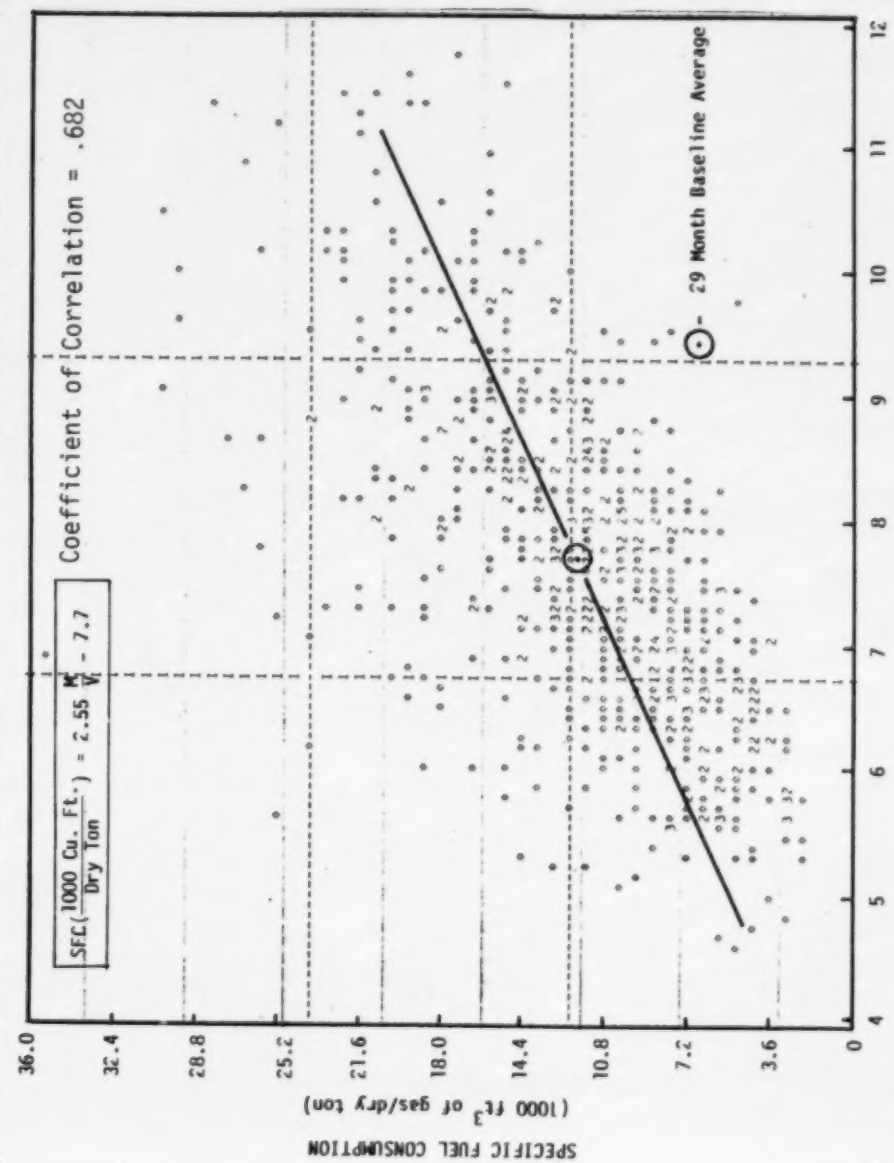

Figure 23. Specific Fuel Consumption for Baseline Period Operations

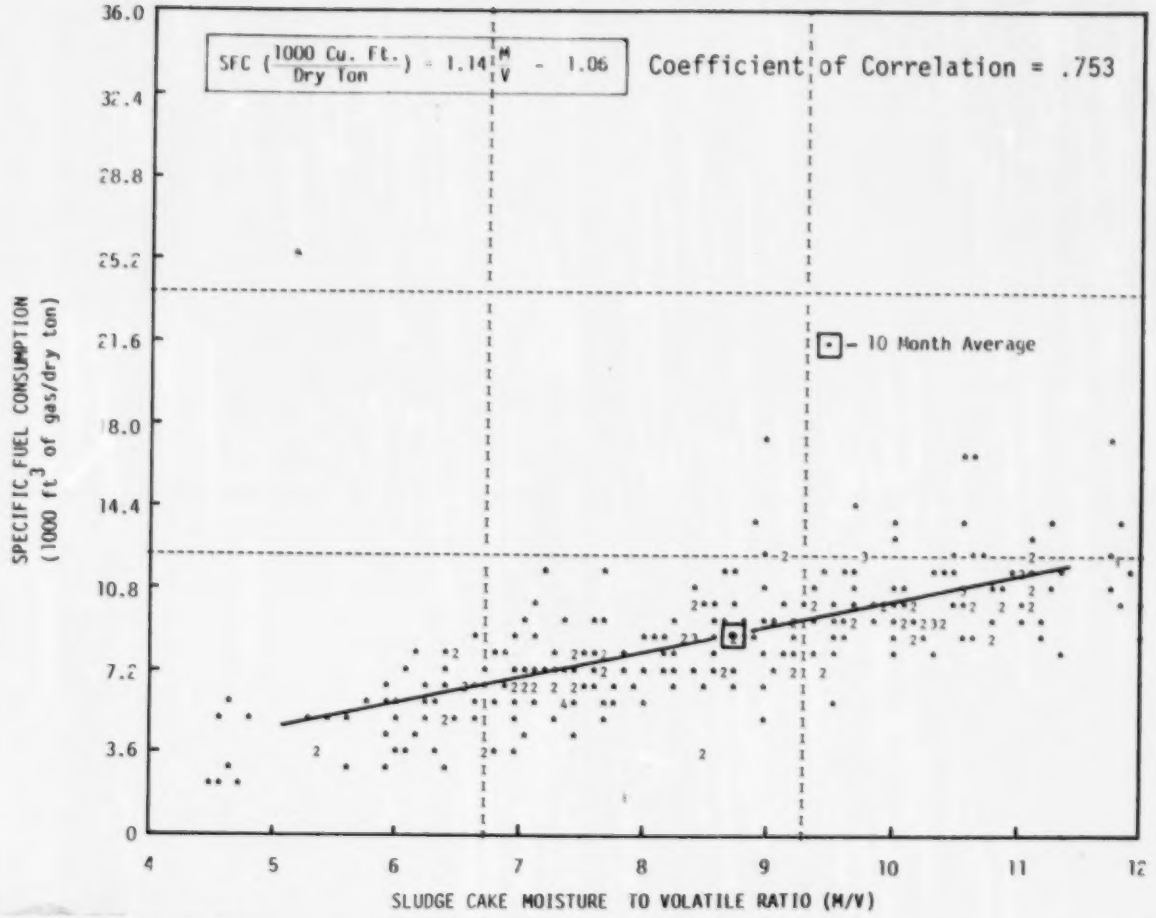

Figure 24. Specific Fuel Consumption for the Ten Month Demonstration Period

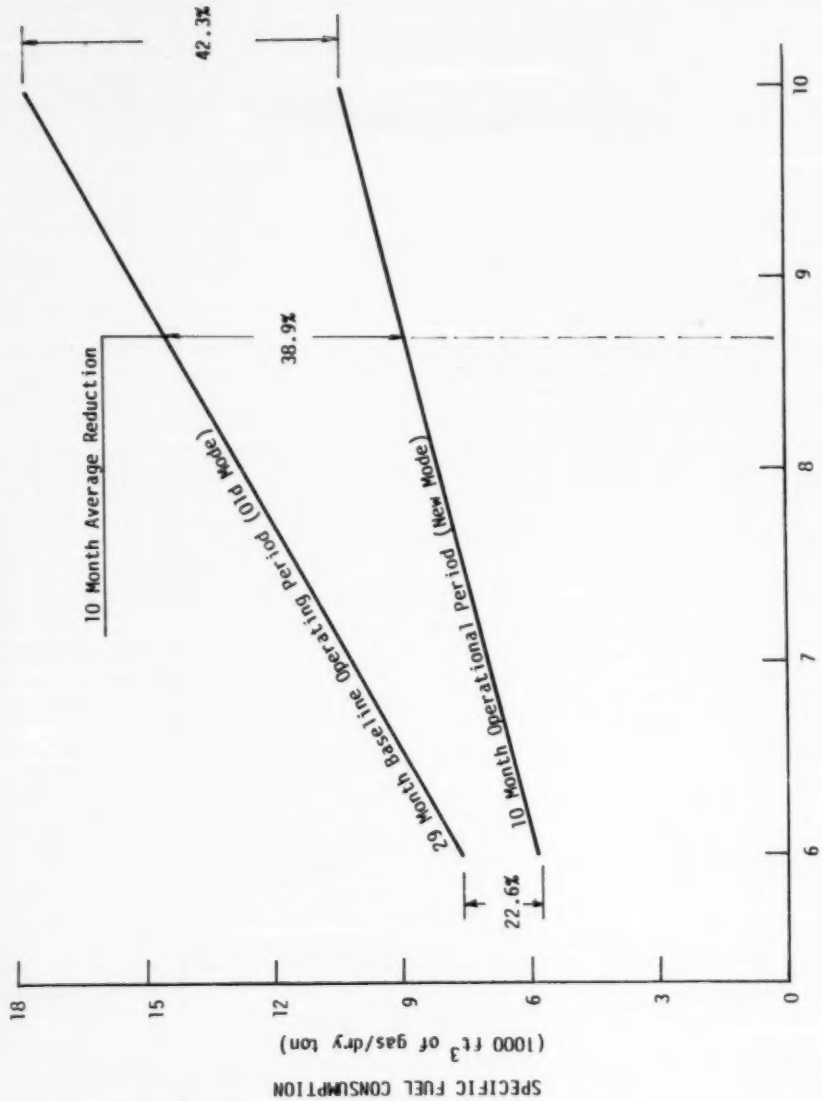

Figure 25. Specific Fuel Consumption Comparison

TABLE 10. PERCENT FUEL REDUCTION ACHIEVED WITH NEW OPERATING MODE BY SLUDGE CAKE M/V RATIO

Sludge Cake M/V Ratio	Specific Fuel Consumption ($1000\ ft^3$/dry ton) Old Mode	New Mode	Percent Difference
6	7,600	5,882	-22.6
7	10,150	6,979	-31.2
8	12,700	8,076	-36.4
9	15,250	9,173	-40.0
10	17,800	10,270	-42.3
Ten month average 8.68	14,434	8,822	-38.9

TABLE 11. AVERAGE DAILY VALUES OF SLUDGE CAKE VARIABLES FOR BOTH TIME PERIODS

Variable	New Mode (10 Months)	Old Mode (29 Months)
Wet Tons	226	202
Dry Tons	35.8	35.7
Percent Moisture	83.9	82.2
Percent Volatiles	62.9	61.9
M/V Ratio	8.68	7.70

TABLE 12. COMPARISON OF STANDBY FUEL CONSUMPTION BEFORE AND AFTER THE NEW MODE

Month	Standby Fuel Used ($1000 ft^3$ of gas) Old Mode 1979/1980	New Mode 1980/1981	
November	5,027	924	
December	3,570	612	
January	300	306	
February	2,369	718	
March	3,419	656	
April	3,359	828	
May	3,198	1,091	
	21,242	5,135	
Average Per Month	3,034	734	-75.8%

SECTION 8

EQUIPMENT RECOMMENDATIONS

Equipment related recommendations for improving the Nashville incinerator operations are summarized in Figure 26 and discussed below in the order of importance.

OXYGEN ANALYZERS

The existing oxygen analyzers did not work due to constant sample probe plugging. This problem can be overcome by "in-situ" type oxygen analyzers. These analyzers avoid the plugging problem by eliminating gas sampling. The oxygen sensor is located directly in the process gas. A zirconium oxide cell is generally employed. This operates at high temperature to enable the analyzer to be located in high temperature zones of the incinerator thereby overcoming the air dilution problem.

The in-situ incinerator oxygen analysis system is shown schematically in Figure 27. A zirconium oxide oxygen probe is located inside the incinerator. The temperature of this cell is maintained at a constant temperature by a controller. Air is constantly supplied to one side of the cell to provide an oxygen reference concentration. Output from the cell is linearized and read out in a control room electronic unit (oxygen readout). A calibration gas system can be designed to serve both analyzers on each incinerator for periodic calibration. Reference and calibration gas flows are very low (1 liter/min), as measured by a panel-mounted rotameter. The estimated cost is $5,000 per analyzer system.

FUEL FLOW RATE METER

Although not used during the Demonstration Test, gas flow rate meters with digital readout in the control room are highly recommended. Estimated cost of these meters is approximately $3,000 per incinerator. Panel mounted flow rate meters would allow the operators to save additional fuel through improved control of the sludge burning level by means of fine fuel flow rate changes. Fuel flow rate information would also aid diagnosis of burner control problems, such as sticking valves, that were encountered many times during the Demonstration Test. These burner control problems caused severe incinerator control problems which resulted in a fuel consumption increase.

POSITIVE DRAFT CONTROL

Accurate draft control is necessary for optimum operation. Too little

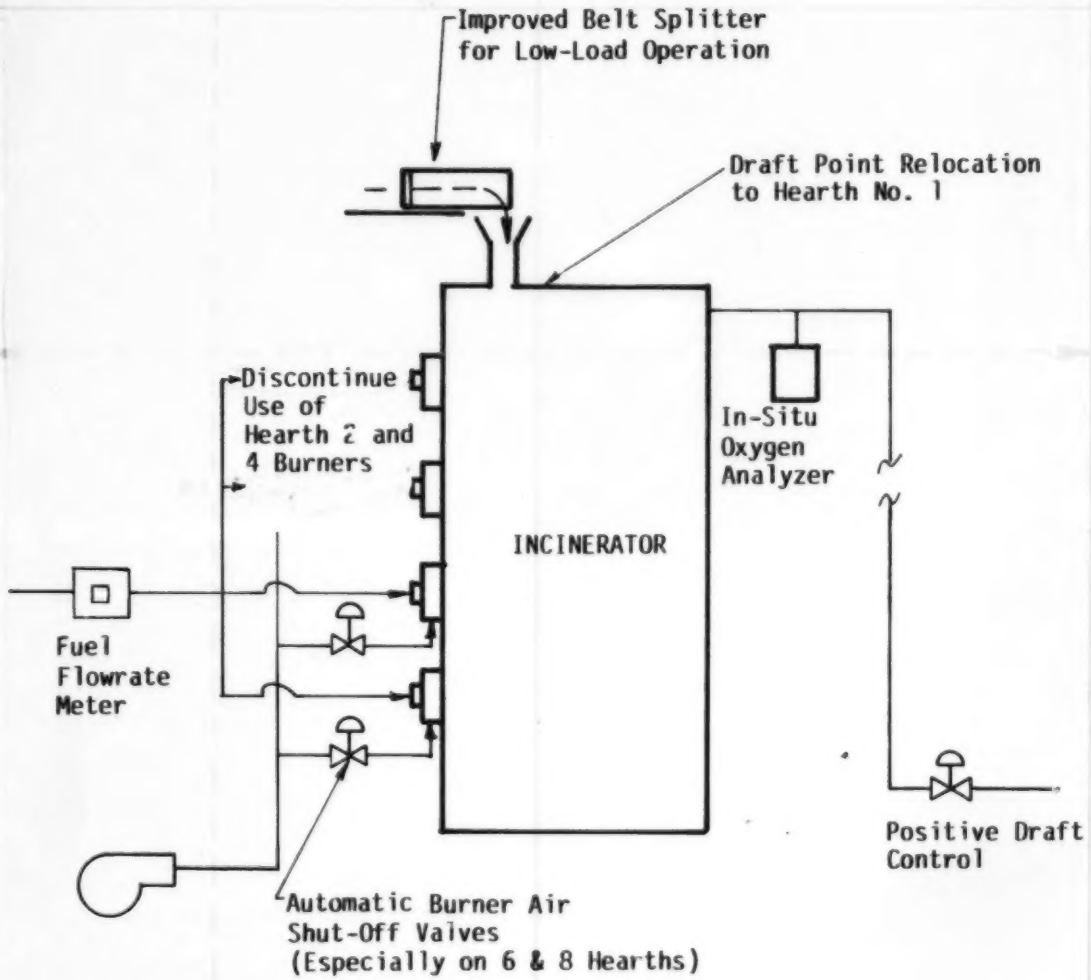

Figure 26. Equipment Recommendations

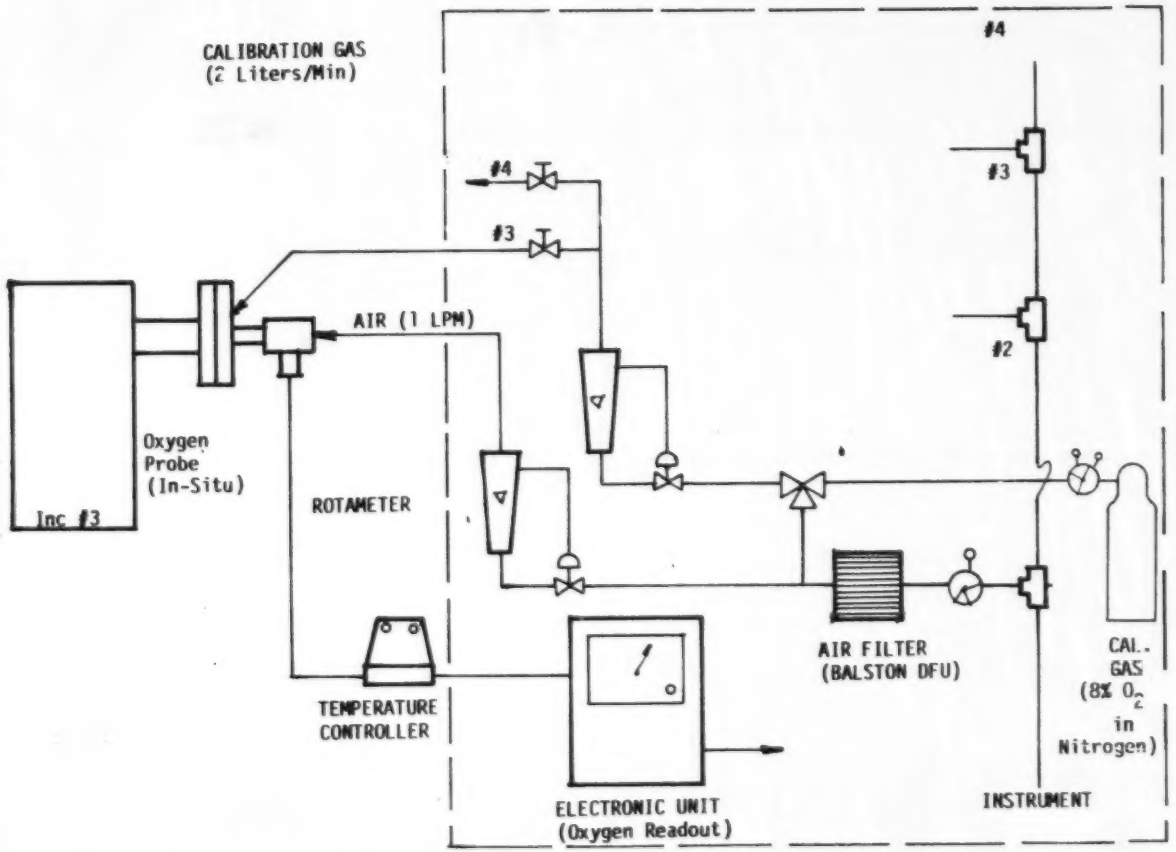

Figure 27. Recommended Incinerator In-Situ Oxygen Analysis System

draft results in smoke in the building; too much draft wastes fuel due to upper hearth air leakage. The current draft control "sticks" and only provides gross control. The control must be repaired, improved, or replaced by an electric control. The latter is recommended to provide accurate control.

DRAFT POINT RELOCATION

The original top draft location in the exhaust duct is not ideal because this location indicates the sum of top hearth draft plus flow loss into the exhaust duct. The net result is that the indicated draft required to operate without smoke in the room varies with incinerator airflow.

To overcome this problem, the draft point should be moved to the top elevation of hearth 1, at a location well-removed from the exhaust duct.

BURNER AIR SHUTOFFS

The Nashville incinerator burners have constant burner airflow regardless of firing rate. The airflow measurements showed that this burner airflow is very large and results in a considerable fuel penalty due to incinerator drying temperature reduction which impedes moisture vaporization. The burner air problem was partly overcome in the Demonstration Test by manually turning off the combustion air valves on most burners not in use. This procedure is not ideal because (1) it requires additional operator effort, (2) burner air pressures cannot be accurately re-established, and most important (3) is somewhat hazardous because of possibility of forgetting to turn burner air back on when required. Automatic burner air shut-off valves would solve this problem and are recommended. These would cost approximately $4,000 per incinerator for hearth 7 and 8 burners. An even better improvement would be new burner controls that modulate burner airflow with firing rate.

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